Assessing watershed-scale consequences of coal surface mines in the headwaters of the Oldman River Watershed (ORW)

Prepared for the Livingstone Landowners Group (LLG), June, 2021

"Water is the most critical issue of our lifetime and our children's lifetime. The health of our waters is the principal measure of how we live on the land".

Luna Leopold

Photo Credit: Bob Costa

"Water is the true wealth in a dry land"

Wallace Stegner

Citation

Stelfox, J.B, and W.F. Donahue. 2021. Assessing watershed scale consequences of coal surface mines in the headwaters of the Oldman River Watershed (ORW). Report prepared for the Livingstone Landowners Group.

Authors

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Dr. Bill Donahue has a long career examining the dynamics between land use and water quality. For the period 2015 to 2019, Dr. Donahue worked for the Government of Alberta as Alberta's Chief Monitoring Officer, the Executive Director of both Monitoring and Science in Alberta Environment and Parks, and as a Visiting Scientist in the University of Alberta's Faculty of Science. Since February, he has begun to analyse Alberta Environment's water quality data from monitoring performed between the late 1990s and 2016 both upstream and downstream of the Luscar, Gregg River, and Cheviot coal mines south of Hinton.

Acknowledgements

The Livingstone Landowners Group is recognized for their longterm vision and for initiating a science-based project examining coal mining in the headwater systems of the Oldman River Watershed (ORW). Funding for the project was kindly provided by an anonymous donor. An advisory committee was struck (Lorne Fitch, John Lawson, Terrence Lazarus, Norma McDougall) who provided client context and offered suggestions on how to best disseminate the findings. The editorial work of Lorne Fitch is greatly appreciated.

This summary report addresses several contextual issues relating to coal mining in the ORW headwaters and is informed by a separate technical report commissioned by the Livingstone Landowners Group on changes in streamflow and water quality in the upper Oldman River watershed (Chernos, M., Goodbrand, A., Straker, J., and MacDonald, R.J. 2021. Changes in streamflow and water quality in the upper Oldman River watershed due to climate change and open-pit coal mining development). We are very grateful for the original research on water quality and quantity completed by these authors.

The insights and encouragement from Laura Laing and John Smith are recognized.

Gord McKenna of McKenna Geotechnical provided helpful insights and context on the dynamics of reclamation of coal mines. Cody Johnson and Monica Field provided assistances in tracking down key historical references of the Crowsnest Pass region. Brooke Kappeler of CPAWS aided in locating key spatial datasets.

Photos of the ORW provided by Bob Costa and Callum Gunn of East Cherry are greatly appreciated.

Report Structure

This overview report contains the key questions, methods, and findings of the project. An independent technical report (Chernos et al. 2021)[1] presents the detailed water supply/demand and water quality analyses. The full reference is Chernos, M., Goodbrand, A., Straker, J., and MacDonald, R.J. 2021. Changes in streamflow and water quality in the upper Oldman River watershed due to climate change and open-pit coal mining development).

Executive Summary

This study was conducted at the request of the [Livingstone Landowners Group] (LLG), which expressed concern about the consequences of large-scale surface mining of coal proposed in the headwaters of the Oldman River Watershed. These new proposed mines represent an abandonment of the Lougheed era coal policy that prohibited mining of coal in Category 2 lands of Alberta's East Slopes. Although the range of LLG's concerns is broad, their central focus for this project is on water quality (selenium), water quantity (supply/demand), and a threatened species (Westslope cutthroat trout) whose conservation depends on watershed integrity.

To address these concerns, we used a simulation approach (integration of the Alces and Raven models) to explore the consequences of different levels of coal mining (no production, medium production (2 mines, ~5.875 MTA/yr), high production (8 mines, ~23.95 MTA/yr)) over a 5-decade period (2022-2072). A "low" coal scenario represented a future without any new coal mining in the ORW. The "medium" scenario examined the two coal mine projects (Grassy Mtn, Tent Mtn) that are most imminent and furthest along in their regulatory approval. The upper limit of the scenarios ("high" production) was limited to the 8 existing proposed coal mine projects that have acquired leases in the ORW, sought investor funding, and submitted details concerning project location, coal reserves, production, and lifespan. Because climate change is an important factor influencing water supply, we also examined the complicating effects of GHG-induced changes to climate and water supply/demand in the ORW.

KEY LEARNINGS

The Extent of Proposed Mines

- If fully developed, the mines would produce ~700 million tonnes of coal over a 50 year horizon and this would create a mine disturbance of at least 9,400 ha (94 km^2). This area of disturbance and volume of coal production would be comparable to that experienced in the neighbouring Elk Valley to the east in British Columbia.
- The 8 mines under planning consideration would involve the movement of more than 6 Billion m^3 of rock and ore, equivalent to 5.4 times the volume of the iconic Crowsnest Mountain.
- This would destroy or alter at least 3,200 ha (32 km^2) of surface water and associated riparian habitat.

Consequences of Mining

Water Quantity

- Water use by coal mines can be a substantial proportion of total flow in headwater streams. Coal mines' demand for water is constant throughout the year. This is a small portion of total flow during spring freshet, but during low-flow periods of late summer and early winter, our simulations of coal mines suggest they may use more than 40% of mean flow in the headwater streams immediately downstream of the mines.
- Coal companies could, in theory, mitigate this problem by storing water from the spring freshet for use during times of lower flow. But in doing so they would create a new problem, because many parts of the ecosystem are dependent on high springtime flows.
- Stream flow is highly variable from year to year, so the impact of water demand from coal mines will be especially severe during drought years. Significant "low precipitation years" of one per decade are not unreasonable to expect based on historical data, and this frequency may increase.
- Under all plausible climate change scenarios modelled, the annual patterns of stream flow will shift, with more water running off during late winter and spring freshet and less during late summer to early winter. Climate change scenarios indicate that the frequency and magnitude of drought years will increase. These factors will further exacerbate the stress of water use from coal mines on headwater streams.
- Reduced in-stream flows because of coal mining will have direct and indirect impact on aquatic communities and ecosystem function.
- At the level of the entire watershed, water is already fully allocated, and during drought years some junior rights holders may not receive their full allocation. Any additional water consumption by mining will

exacerbate this conflict and may result in additional water shortages. This problem is likely to worsen if, as most climate models predict, climate change increases frequency of droughts.

Water Quality

- The ability of mining companies to prevent release of selenium from their operations is critically important to water quality within the watershed. According to our simulations, mines would have to prevent release of 95% of all selenium to meet all water quality standards in the upper reaches of the watershed, and even higher attenuation levels would be needed to prevent harm to the smallest streams nearest to the mines. Even as far downstream as Lethbridge, 90% attenuation levels would be required to meet standards for protection of aquatic life. **We have been unable to find evidence that companies mining high-selenium coal deposits of this type can consistently achieve these attenuation levels at full operational scale.** Any claims by mining companies that they can do so — not just in laboratory demonstrations, but at actual operational scale — must therefore be considered unproven and subject to the greatest skepticism.
- Selenium loads can be expected to be especially high during periods of low stream flow in late summer and early winter, when there is less water to dilute the constant discharge of selenium.
- Coal mines in the Elk Valley of BC, just across the border — which, importantly, are in the same geological formation as the proposed mines — have resulted in substantial selenium release and resulting toxicity to aquatic communities, reduced abundance of Westslope cutthroat trout (WSCT), and reduced drinking water quality. **The onus must be on mining companies to prove beyond doubt that any new mines would not experience the same problems**.
- Coal mines further north from the ORW, in the McLeod River drainage, have similarly led to release of selenium and other pollutants such as sodium, aluminum, calcite, and nitrate, many of which exceed government safety guidelines for some or all of aquatic habitat and irrigation use.
- Moving downstream, selenium concentrations are likely to decline as additional tributaries add to stream and river flow. However, even as far downstream as Lethbridge, our simulations suggest that attenuation levels of 90% will be necessary
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- y to meet regulatory guidelines for aquatic life.
- Effects of moderately elevated levels of selenium on humans and other organisms are poorly understood, so even concentrations that meet current regulatory guidelines may have unrealized health effects.
- We have not modelled the effects of coal mining on sediment load to streams, but this requires attention.

Landscape and Species at Risk

- The proposed mines are situated within some of the best remaining habitat for threatened Westslope Cutthroat Trout. Since mining activity will directly remove all or nearly all vegetation, streams, and fish habitat within the disturbance footprints, this will lead to the loss of ~3,200 ha of riparian habitat. In turn, this will cause a substantial reduction in amount and suitability of habitat for this species, and its population would be expected to decline significantly. This is, in fact, what has been observed in the neighbouring Elk Valley of southeast BC. Similar dynamics are likely to unfold for threatened bull trout populations, as well.
- The proposed mines are situated within lands classified by Govts of Alberta/Canada as "critical wildlife" habitat, especially as connectivity corridors for species at risk such as Grizzly bear, WSCT and bull trout.
- The proposed mines also threaten to interrupt existing connectivity of the entire Yellowstone-to-Yukon ecosystem, a connected series of protected areas and otherwise relatively pristine habitat stretching from Wyoming to the Yukon. The Crowsnest Pass region north of Highway 3 is one of the few parts of this entire corridor that lacks large tracts of formally protected habitat. Until now, this has not caused problems, because human land uses in this region have been relatively light, allowing the region to achieve much of its ecological potential. That would no longer be true if regional coal mining were to be developed within this corridor.
- The upper reaches of the ORW (as seen, for example, from Highway 22, the iconic Cowboy Trail) include some of the most spectacular vistas along the East Slopes. For 150 years, the ranching community of the upper ORW has maintained this landscape in its present condition. The proposed coal mines would consume what these families have worked so hard to conserve.

Habitat Reclamation

- Coal mines have no track record of reclaiming old mine sites to a level that fully restores previous ecological function. Reclamation often consists of re-sculpting topography and revegetating mine sites, which does not necessarily restore previous hydrology or habitat suitability.
- There is currently no technology to restore native high-elevation fescue grasslands, a significant habitat type within the footprint of the proposed mines.
- Coal mining companies, just like the oil and gas industry, have a troubled history of reclamation. As with orphan wells in the oil and gas industry, many old mines such as Grassy Mtn and Tent Mtn were left largely unreclaimed, often because companies sold off their assets and the new owners declared bankruptcy, leaving the government and public with the reclamation liability. Reclamation bonds posted by mining companies are typically inadequate to fund basic reclamation, let alone high-quality efforts.
- Our simulation estimates suggest that only about 25% of disturbed mine area in the ORW will be reclaimed by the end of the 50-year study period, leaving a substantial reclamation bill for the future. Under the medium-coal scenario, this future reclamation liability is projected at between ~$30 M and $210 M, while under the high-coal scenario, it is projected at between ~$175 M and $1.23 B.

Climate Change and Carbon-Reduction Commitments

- Our simulations suggest that development of the proposed mines could contribute an additional 1,908 MT CO_2e over the course of our 50-year timeframe, by conservative estimates. This is roughly equivalent to 7 years of Alberta's current total CO_2e emissions.
- The magnitude of these emissions would greatly reduce the ability of Alberta and Canada as a whole to meet the CO_2-reduction targets they have already committed to, let alone more stringent future commitments.
- The International Energy Agency (IEA) has developed a plausible scenario in which existing sources of metallurgical coal would be sufficient to meet global needs through 2050. **There could thus be no short-term need for development of the proposed mines — they are not essential for continued global steel production**.
- Newer steel-making technologies, some of which are already coming into use, should further reduce the need for metallurgical coal. The proposed mines thus are not essential, and are likely to become obsolete within their working lifetime.

Decision-Making Process

- The Alberta Land Use Framework of the Government of Alberta mandates that an exhaustive cumulative effects assessment is required before approving regional coal mining of the scale considered in this report.
- **No such assessment has yet taken place for the ORW**. Existing assessments of the mine proposals have not examined the full suite of land uses and natural disturbance regimes or the effect of the mines on the integrated natural ecosystem. They also have failed to include consultation with the full range of stakeholder groups, including landowners, First Nations, recreational users and others. This failure can be seen from the loud and surprised public outcry when mining plans were announced in 2020. Nor have existing assessments looked at the proper spatial and temporal scale that encompasses all proposed mines, rather than examining each project independently, as if it were the only one being considered.
- Existing assessments have not considered the effects of climate change on precipitation, stream flows, or water needs. **With effects of climate change already being felt within the region, this is a critical omission.**
- Existing assessments have not considered other economically important activities within the region, and the effect of the proposed mines on those activities. Notably, the tourism industry (which provides an economic return of more than $200M annually in the adjacent and comparable Kananaskis country) would likely be severely impaired by the presence of extensive surface mining.
- Until meaningful cumulative effects assessments have been conducted, neither mining companies nor regulatory bodies can claim to fully understand the consequences of the mines under consideration.
- For further discussion of deficiencies in the Government of Alberta decision making process, see the independent submission by Fitch et al. (2021) entitled Insights in coal development from five retired fish and wildlife biologists: submission to the Alberta Coal Policy Committee.

Recommendations

Coal mining in the headwaters of the Oldman River Watershed should not proceed until robust answers to critical questions are provided and discussed broadly by the full stakeholder community. Specifically the Alberta government should not consider proposals for coal mining in Alberta's East Slopes until it has commissioned, received, and understood studies of the following key areas:

- Rigorous cost/benefit analyses that incorporate a full suite of natural capital attributes, including water.
- A full regional cumulative effects assessment involving all land uses and natural disturbances in the ORW.
- A careful examination of water supply and demand dynamics through the lens of climate change.
- Quantification of background selenium levels in water and food chains of wildlife and livestock species.
- Comprehensive assessment of projected airborne emissions associated with coal projects.
- Improved physiological understanding of how selenium and other elements affect invertebrate, vertebrate, and human health.
- Assessment of the long-term economic viability and social consequences of coking coal if the steel sector moves toward other energy sources.

Caveats

Because of scheduling and budget constraints, the approach and focus of our research (both the technical report and the summary report) was strategic in spatial and temporal scale and systems complexity. Whereas we believe that our findings are robust at the scales we have explored, and at the level of watershed system dis-aggregation we have examined, it would be highly advisable for the Government of Alberta, industry, and academic institutions to explore these dynamics with other complementary approaches, particularly those that adopt a less aggregative approach to spatial scales and systems complexity. Such additional research is likely to reveal patterns that support or challenge our findings, and help society better understand the magnitude of risk posed by expansive surface coal mining in Alberta's East Slopes. Whereas this project focuses primarily on the interface between proposed coal mining and water, both the report authors and LLG recognize that all land uses in the ORW affect water quality and quantity. Addressing existing issues of water quality and quantity in the ORW will require decades of innovative land use practices. Adding additional stresses to an already challenged watershed, by placing large coal mines in headwater basins, would only complicate this challenge further.

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Historical Context to the Coal Issue

The Request of the Livingstone Landowners Group (LLG)

This project, and the report it has produced, was born out of concern about imminent coal surface mining in the headwaters of the Oldman River watershed (ORW). The Livingstone Landowners Group (LLG[2]; Figure 1) requested of the authors an independent assessment of the following key concerns:

Will a coal mining land use trajectory in the headwaters of the Oldman River Basin contribute to:

- Local and/or watershed-scale selenium toxicity?
- Local and/or watershed-scale water supply/demand issues?
- Local and/or watershed-scale landscape disturbance and fragmentation issues?
- Local and/or watershed-scale changes in risk to threatened species (Westslope cutthroat trout)?

The LLG also wanted insight into how answers to these questions might change in light of climate change projections and expected changes in existing historical land uses (human population, irrigation area, cattle population). Membership of LLG felt that the current regulatory process relating to Grassy Mountain Coal Mining Project, overseen by the Alberta Energy Regulator and the Government of Alberta, had not answered these questions adequately.

The families who reside in these headwaters felt it critical that objective and scientifically-defensible messages be conveyed to each of the following audiences:

- All community members up and down the East Slopes that may be directly affected by coal mining
- Albertans in general to help them understand the important role the East Slopes play to water dynamics
- The recently formed Coal Consultation Committee
- The Governments of Canada and Alberta

This report is written to be readable by the public in the ORW and more broadly in Alberta. More technical components of the report are included as appendices at the back of the report. Where possible, referenced organizations and programs are shown in highlighted hyperlinks to assist readers in locating additional online information.

Figure 1. The Livingstone Landowners Group (LLG) have been an active stakeholder in all land use matters relating to watershed sustainability in Alberta's southern East Slopes.

The Oldman River Watershed

The Oldman River Watershed (ORW; Figure 2) of southwest Alberta is an iconic landscape whose headwaters have supported First Nation (Aputosi Pii'Kani) peoples since the retreat of glaciers ~8,000 ybp[3], provide exceptional natural capital to Albertans, yield significant volumes of high-quality water for downstream land uses (Figure 3), and serve as a premier destination for front and back-country recreation and tourism.

Today, the ORW is home to 167,383 people[4] (6.1 people/km^2) distributed across 22 urban municipalities, 11 rural municipalities, and 2 First Nation Reserves (Figure 2). During the past 3 decades, the population has been growing at an average annual rate of 2.1%. Within 5 decades, the population is expected to grow to 355,000.

Throughout the past century, the low elevation and drier portions of the ORW have been increasingly transformed by a growing human population and overlapping land uses (cattle grazing, dryland crops, irrigation crops, mining, energy sector, residential, recreation). These burgeoning human populations and their land uses require adequate water quantity and quality to exist. With these expanding population and land use has come increasing recognition of the fragile balance between water supply and demand within this semi-arid watershed. In recognition of the scarcity of water, the Government of Alberta in 2006 "closed" the ORW (and the larger South Saskatchewan basin), to any additional net allocation of water[5]. This inter-generational discussion about the benefits (jobs, royalties, GDP) and liabilities of land use (reduced levels of water quality, water quantity, air quality, soil organics, landscape integrity) has led to community recognition that there is a very real limit to the sustainability of natural capital within the ORW and reinforced the need to carefully assess these trade-offs before additional land uses are permitted to occur.

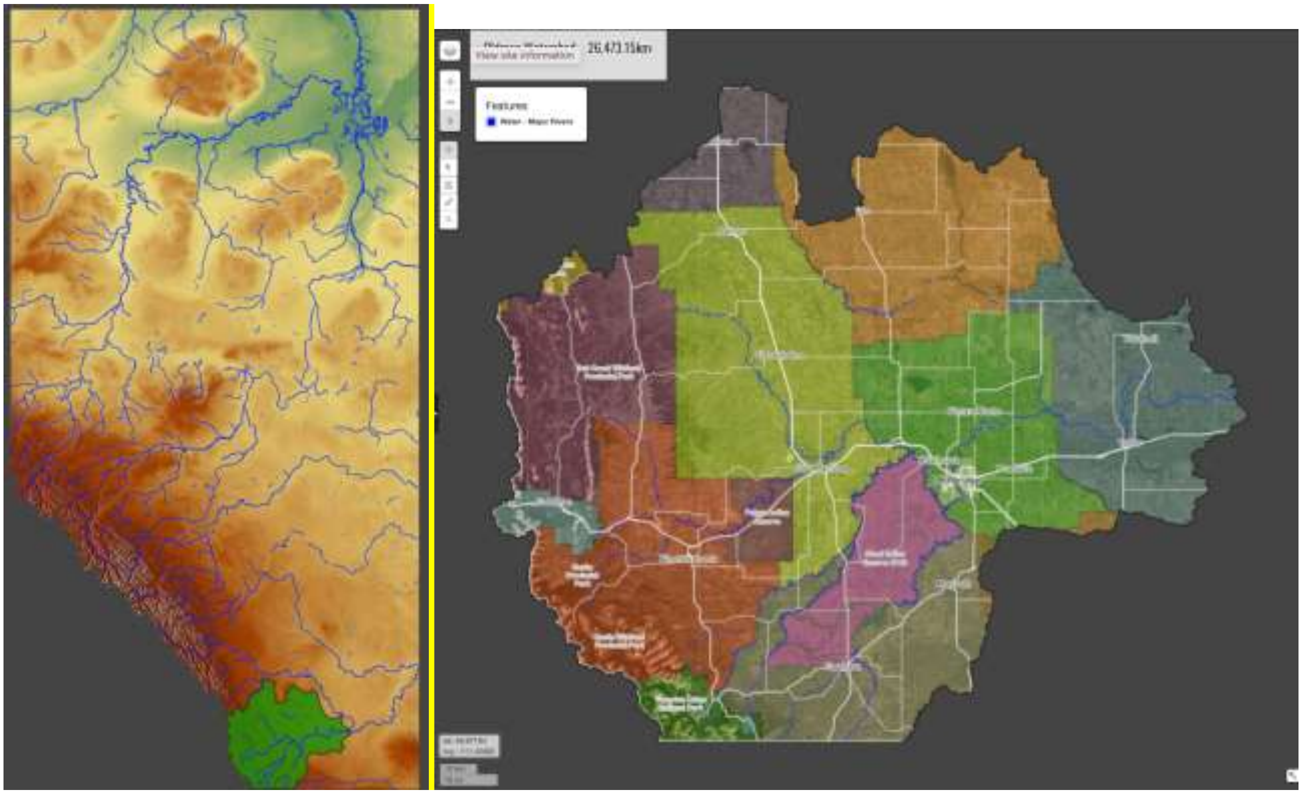

Figure 2. Location of the Oldman River Watershed (ORW) in southwest Alberta (left) and the major settlements and municipalities within the ORW.

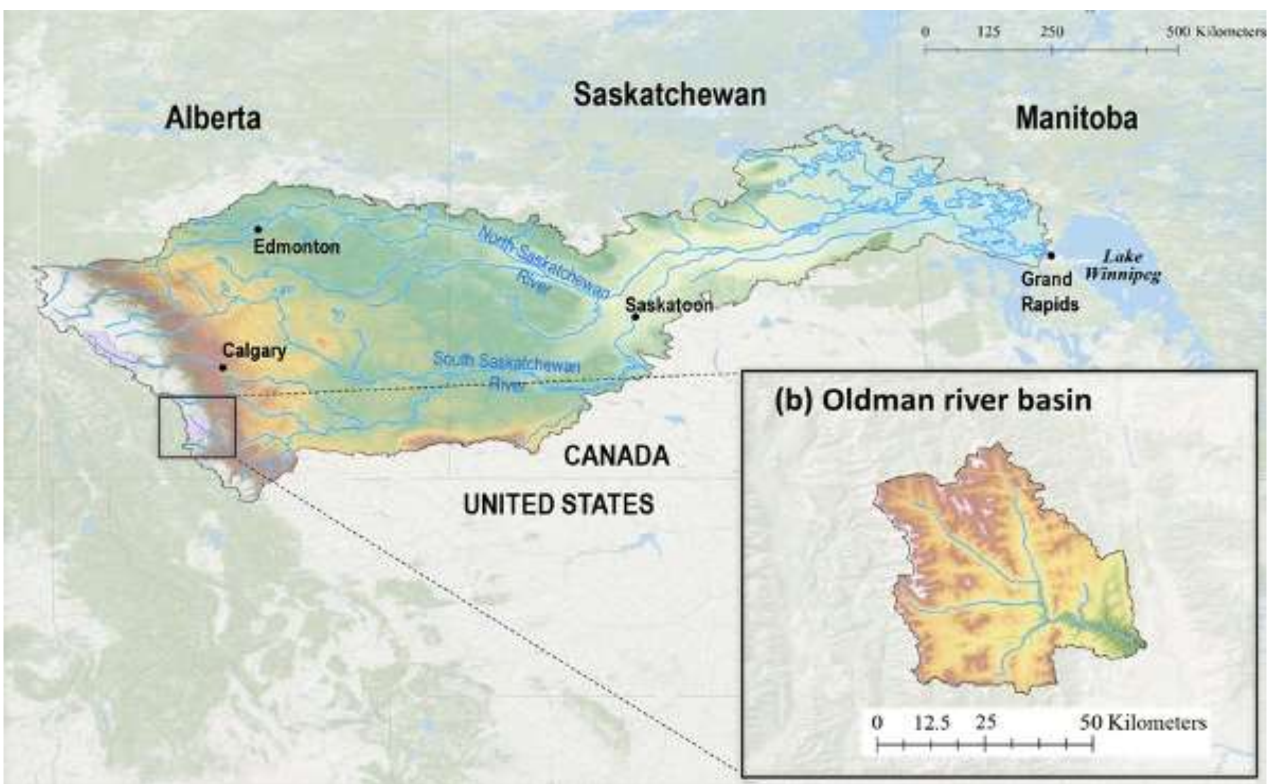

Figure 3. The headwater position of the Oldman River Watershed in the Saskatchewan River basin that provides water to southern Alberta, Southern Saskatchewan and Manitoba. Source: Oldman Watershed Council website.

The Issue of Water Supply, Water Quality, and Headwater Protection

The critical importance of the ORW, and Alberta's East Slopes in general, for provision of water quantity, water quality, and functioning foothill/mountain ecosystems, was first described by Euro-Canadians in 1911, when the Government of Canada established the Rocky Mountain Forest Reserve[6]. This resource management mandate was subsequently transferred from federal to provincial governments in the Natural Resources Transfer Act of 1930[7], although the Government of Canada would remain active in management until after World War II[8]. The Eastern Rockies Forest Conservation Board[9], comprised of both federal and provincial members, was established in 1947 to ensure that land uses in the region did not jeopardize the water supply of the Saskatchewan River, to which the ORW belongs. The Board was dissolved in 1973 and at that juncture management of the East Slopes was the sole responsibility of the provincial government[10]. The primacy of watershed protection was further enshrined by Premier Peter Lougheed's 1976 Alberta Coal Policy, which prohibited coal exploration and extraction across large tracts of the East Slopes. Additional historical narrative of resource management in Alberta's East Slopes, and its focus on water protection, is provided by Brownsey and Rayner (2009)[11]. The key documents that describe the historical emphasis on water integrity in the East Slopes are shown in Figure 4.

Increasing scrutiny of the activities of land uses, and the status of the natural resources on which they depend, has been completed through numerous public engagement strategies in the ORW (Environment Conservation Authority (1974), Alberta Land Use Framework (2014)[12,13], Southern Foothills Study (2015)[14]). Not-for-profit watershed organizations like the Oldman Watershed Council[15] exist to disseminate information and provide public discourse on the key function of these headwater basins.

Previous research on water supply/demand and water quality on the ORW[16] (Byrne et al., 2016) has reminded watershed residents of the longterm declining trends in both water quantity and quality. Increasingly, the residents of Alberta's East Slopes have recognized that they must abandon historical land use ideologies best described as "everything, everywhere, all the time". What used to be viewed as vast landscapes with sparse land use pressures is now recognized as a crowded landscape where land uses increasingly compete for progressively scarcer resources of water, air, carbon, wildlife, and land.

The residents of the ORW are aware of the potential scarcity of future water resources and have expressed their concern that existing land uses should not be placed at risk by new headwater land uses that either affect the quality of water supply or have a significant water demand of their own[17]. It is for this reason that Albertans in general, and citizens of the ORW specifically, endorse the importance of expanded protection of the headwaters of the East Slopes[18].

A key building block to the sustainability management strategy of the East Slopes is its Protected Area components[19,20,21]. A recent survey by social and research firm Leger, commissioned by CPAWS and LLG[22], indicated that ~76% of Albertans wish to see an expansion of protected areas in Alberta's East Slopes. The same poll revealed that 66% of Albertans oppose new coal mining in the East Slopes. These views were largely consistent across various geographic, age, and income demographics.

Clearly, Albertans recognize the inherent multi-generational value of these headwater systems (Figure 5) and the key role they play to downstream land uses (Figure 6) if protected areas and appropriate management practices are allowed to maintain their ecological function. The complex interaction between land use and watershed function, and the host of issues that challenge this delicate balance, are narrated in an LLG-sponsored video by landscape ecologist Kevin Van Tighem and watershed ecologist Lorne Fitch[23].

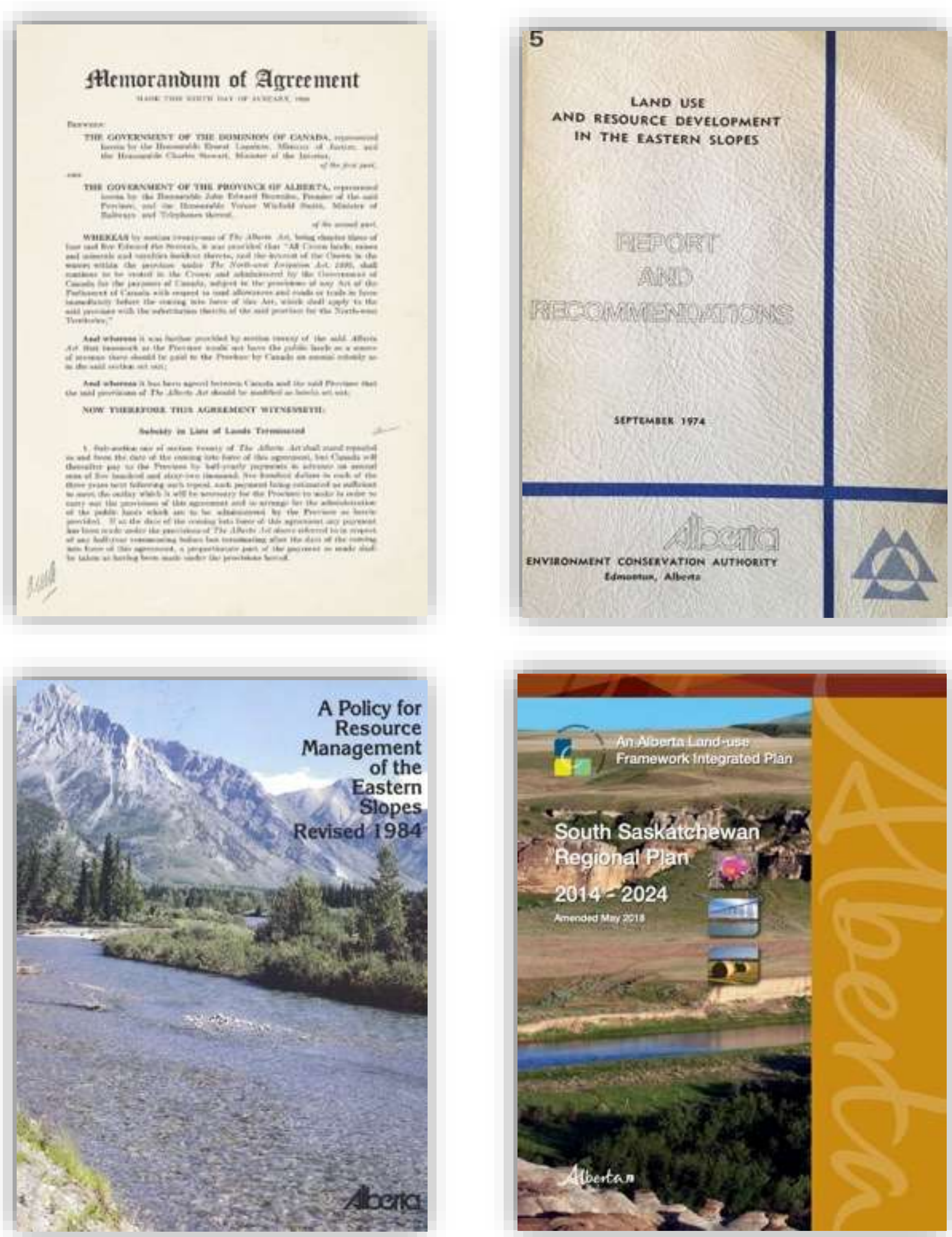

Figure 4. Since the inception of the Province of Alberta, there have been several multi-stakeholder initiatives that have examined the issue of land use within Alberta's East Slopes. Examples include the Natural Resources Transfer Act (1930; upper left), the Environmental Conservation Authority (1974; upper right), the 1984 Policy for Resources Management of the Eastern Slopes (lower left), and the 2014 South Saskatchewan Plan of the Alberta Land Use Management Framework. Each of these documents emphasize the critical importance of water and the need to maintain this critical resource.

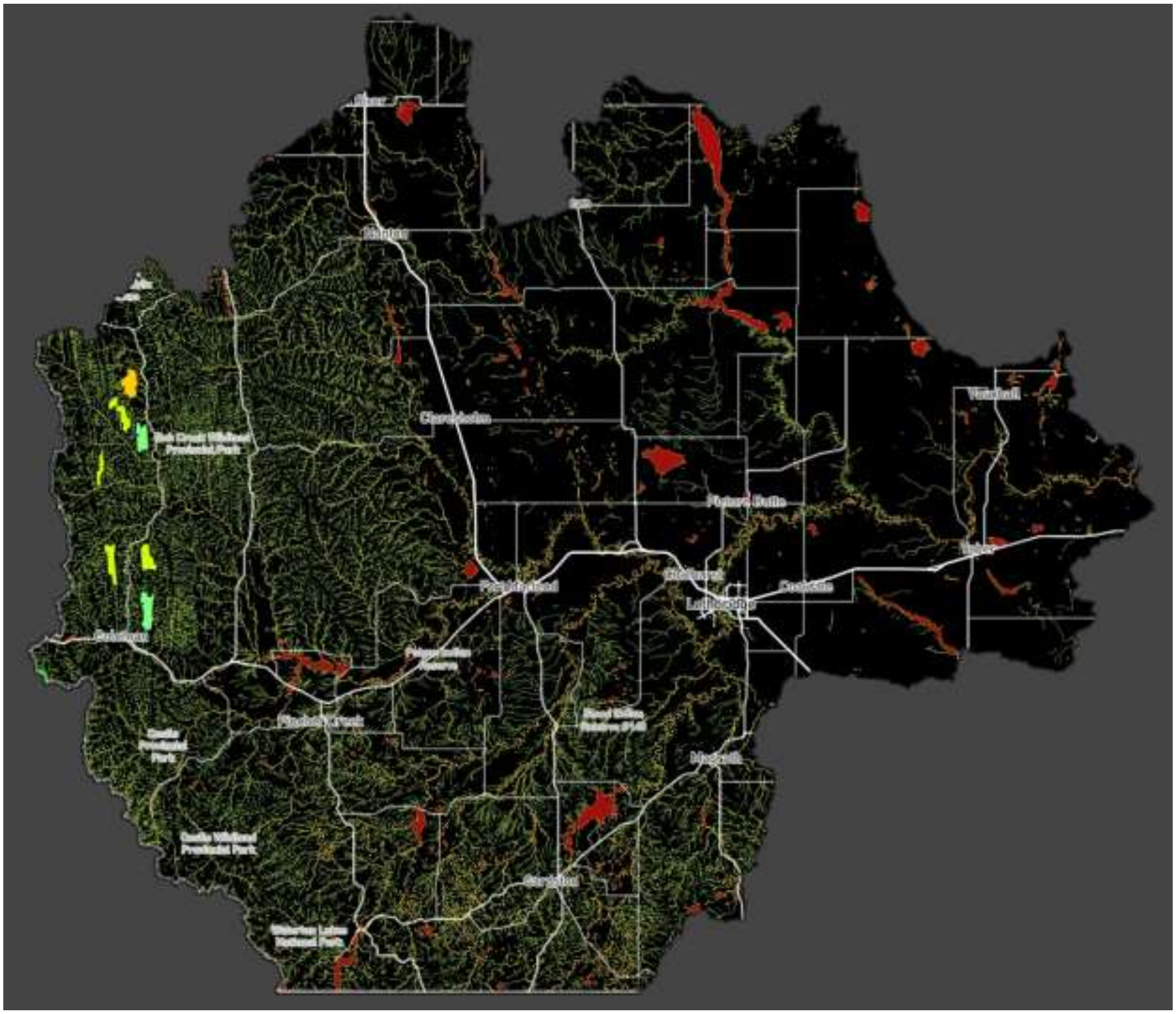

Figure 5. The surface hydrology of the ORW is comprised of innumerable small (often intermittent) creeks that feed into streams, which in turn, feed into mainstem rivers whose flow provides water to thirsty downstream land uses. The red polygons represent standing water (including reservoirs) while yellow-ish lines illustrate the dendritic network of streams in the headwaters of the ORW. The green-ish polygons in the headwaters show the boundaries of the eight coal mines proposed for the ORW headwaters that were simulated as part of this project.

Figure 6. Cattle grazing and irrigated cropping are important and historic land uses in the ORW. The viability of both land-use sectors depends on reliable access to water of good quality and quantity.

The Prospect of a Large Coal Mining Trajectory in the East Slopes

Coal mining has a long history in Alberta. In 1976, however, the Alberta provincial government, under Premier Peter Lougheed, enacted a policy that prohibited coal mining in Category 2 lands in Alberta's East Slopes. This ban came from their recognition that these lands were of critical hydrological importance as the source of the great majority of Alberta's water resources. The policy recognized that the primary purpose of these headwater regions is to ensure critical watershed function for all downstream users.

In May of 2020, the current government of Alberta rescinded this Lougheed era policy and opened up Category 2 lands in the East Slopes to exploration and development of surface coal mining. Shortly thereafter, a series of industry-based articles emerged show casing capital investment interests from Australian corporations[24,25], and promoting the economic benefits of this new resource extraction trajectory.

This new policy decision of the Kenney administration also catalysed public outrage (albertaeasternslopes.ca) and much negative scientific and policy commentary (see Nikiforuk[26,27,28]; Lorne Fitch[29,30]; Kevin Van Tighem[31,32]; David Luff[33]), engendered public information campaigns by environmental organizations (CPAWS[34], AWA), the ranching (savethemountainrange[35]) and First Nation communities (Niitsitapi Water Protectors)[36], and encouraged well-known artists (Corb Lund[37,38] and Amber Marshall[39,40]) to express alarm to their social media followers. As a result of this public outcry, the Government nominally cancelled its short-lived new coal policy direction[41] and launched a formal public consultation process[42].

Although the original Coal Policy has been "re-instated", it was clear that its current wording still functionally encouraged a new chapter of coal licenses (Figure 9), exploration, and surface coal mining in Alberta's East Slopes, including on those sensitive headwater landscapes classified as Category 2 (Figure 9). Following an online public questionnaire enlisting concerns by Albertans for coal mining in the East Slopes (March-April 2021) the Government of Alberta cancelled ongoing coal exploration licenses[43] in late April 2021 until the conclusion of a formal East Slopes coal consultation process[44].

Shortly after the revoking of the 1976 Alberta Foothills Coal policy in the spring of 2020, the Alberta general public became aware of the geographic extent and magnitude of surface coal mining interest by corporations from Australia and elsewhere. The general geographic extent of these proposals in the ORW headwaters is significant (Figure 9; right map). The central proponents for coal mining in the ORW are Riversdale Resources (Grassy Mountain project), Montem Resources (Tent Mountain project), the Atrum proposals (Isolation South, Elan South), Warburton's Cabin Ridge project, and Montem's northern proposals (Isola, 4-Stack, Chinook). It is these 8 prospective coal mines that are the subject of this study (Figure 10). The combined area of leases associated with these mining proposals is 51,297 ha (512.9 km^2;Table 1). Although the ownerships of leases, and the timing of project submissions and exploration licenses continues to evolve, there exists sufficient spatial and temporal information to build an "exploratory" simulation exercise to assess the benefits and liabilities of a surface coal mining trajectory in the ORW region. Selected summaries of these proposed coal mine projects are provided (Appendix B. Additional Details of Prospective Coal Mine Details).

Figure 7. Recent policy changes by the Government of Alberta encourage surface mining for coal in Alberta's East Slopes.

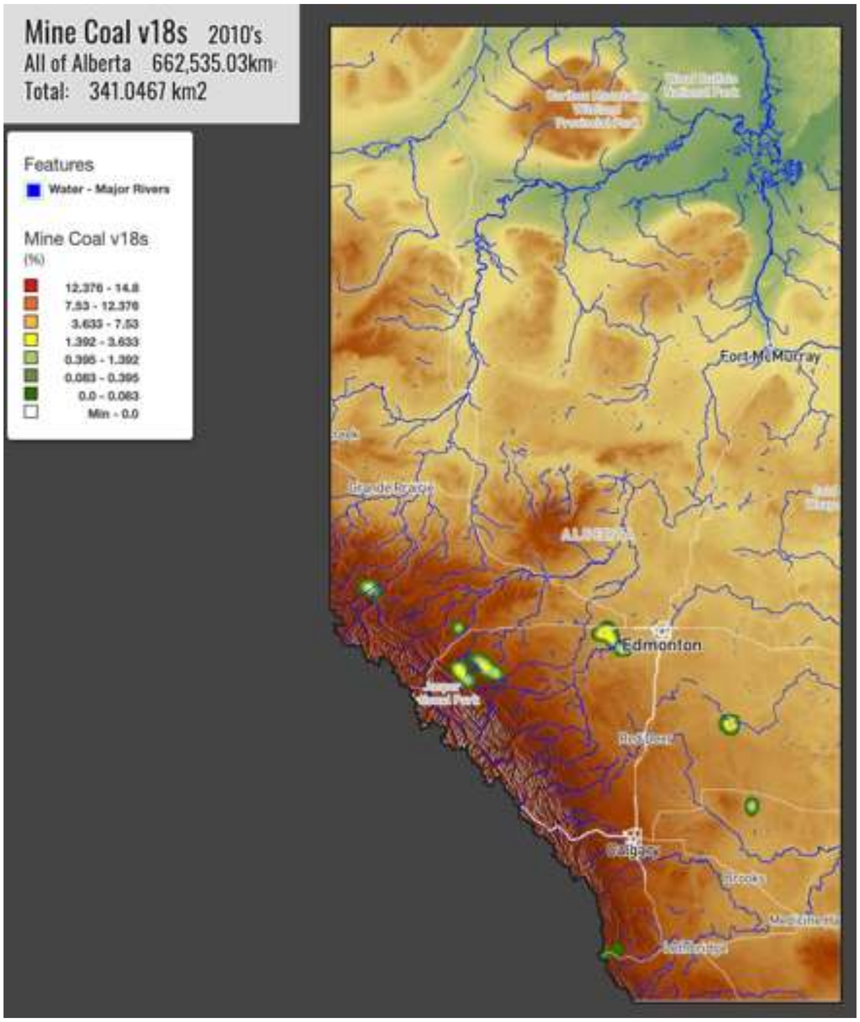

Figure 8. Existing coal mine footprint (34,105 ha; 34.1 km²) in Alberta in 2018. Source: Alces Online and ABMI 2019.

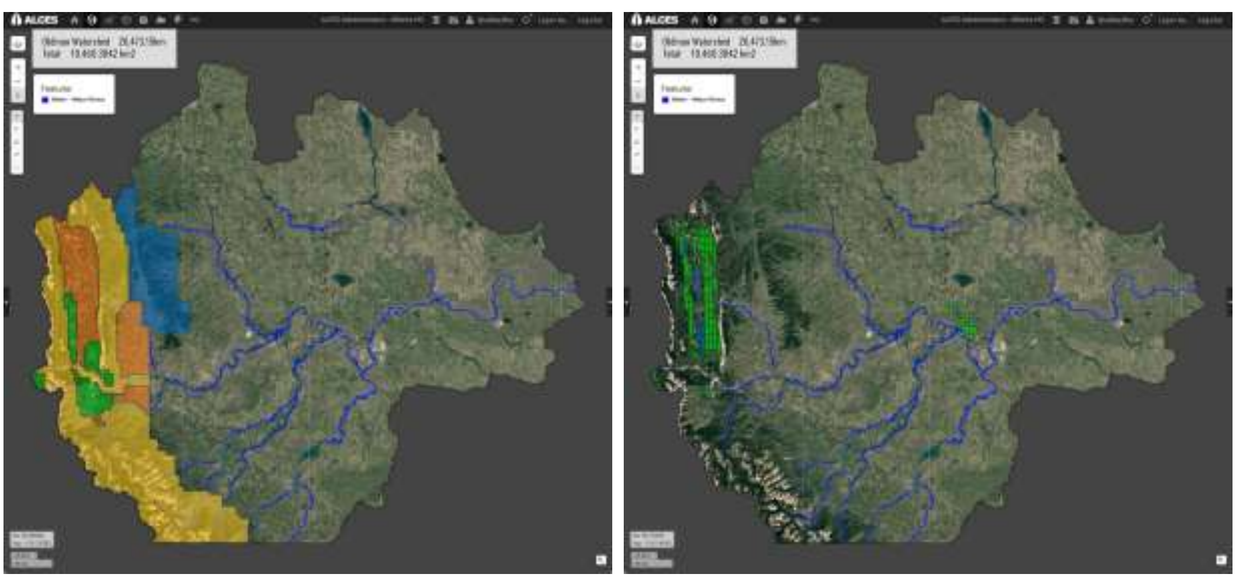

Figure 9. Existing coal categories (left) and coal agreements (right; shown in green and blue grids) in the headwaters of the ORW. The dark orange region in the left map represents Category 2 coal lands. It is these lands that the prospective coal mines are projected to occur in. Source: Alces Online.

Table 1. Key summary values of eight prospective coal mines in the ORW that were explored in this study.

Prospective Coal Project Name	Low Growth Scenario	Medium Growth Scenario	High Growth Scenario	Coal Project Lease Area (ha)	Cumulative Area of Disturbance (ha)	Proposed Lifespan yrs	Ave Annual Coal Production (tonne/yr)	Maximum Annual Coal Production (tonne/yr)	Cumulative Coal Production (MT)	Proven or Indicated Coal Resources (tonnes)
Grassy Mountain Coal Project		x	x	8,330	1,244	25	4,026,609	4,706,000	92,612,000	1,125,000,000
Tent Mountain Project		x	x	1,931	364	14	1,020,639	1,198,600	14,288,950	22,000,000
Elan South Coal Project			x	13,000	1,261	22	3,997,701	5,293,179	91,947,116	47,000,000
Isolation South Coal Project			x	6,239	1,278	21	5,528,137	6,000,000	127,147,151	112,000,000
Cabin Ridge Project Ltd			x	5,000	1,276	23	3,997,701	5,293,179	91,947,116	100,000,000
Isola Coal Project			x	4,832	1,354	25	3,997,701	5,293,179	91,947,116	100,000,000
4-Stack Coal Project			x	1,965	1,235	25	3,997,701	5,293,179	91,947,116	100,000,000
Chinook (Vicary) Coal Project			x	10,000	1,334	25	3,997,701	5,293,179	91,947,116	149,000,000
Totals				51,297	9,346		13,875,674	23,948,137	593,783,680	1,755,000,000

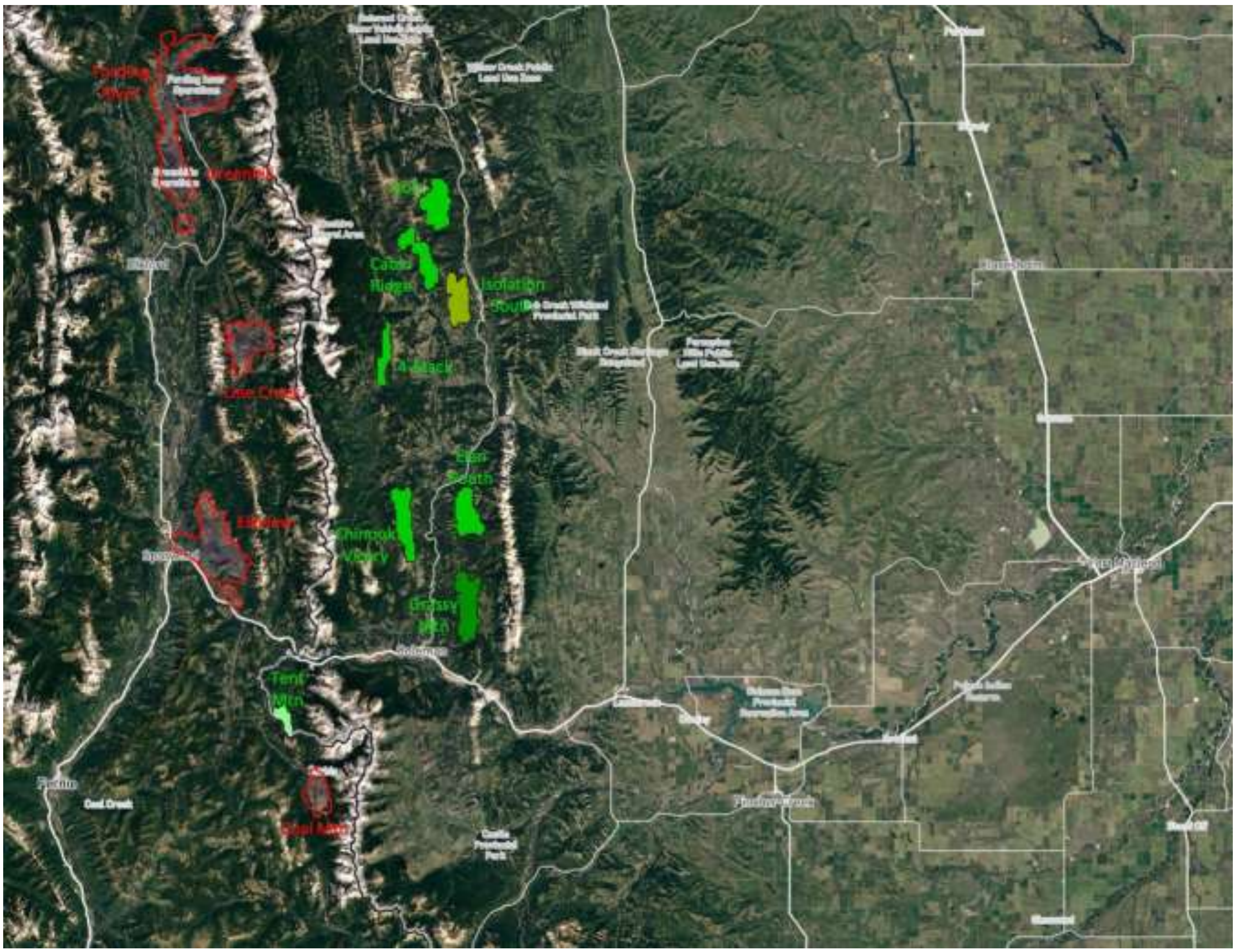

Figure 10. Eight prospective coal mine projects in the headwaters of the Oldman River Watershed (green). This image also shows the visible boundary of direct footprint of existing coal mines in the Elk Valley of southeast BC.

Coal Geology

The geological history of the coalfields in the Oldman River basin headwaters is described by Smith, Cameron, and Bustin[45,46] of the Alberta Geological Survey[47]. These coal seams are part of the Jurassic-Cretaceous Mist Mountain Formation (Kootenay Group) which extends from the Elk Valley region of SE BC to the SW region of Alberta (Figure 11). Smith et al. describe these seams as deposits with a broad coastal plain environment during the first of two major episodes of the Columbian Orogeny (Stott, 1984; Gibson, 1985a). The Mist Mountain Formation is comprised of inter-bedded deposits of coal, siltstone, mudstone and sandstone of up to 1,000 m thick. Coal seams are up to 18 m thick and change in rank from a south to north orientation.

It is important to know that the geological properties of coal in the ORW are very similar to those coal seams mined in the Elk Valley of SE BC that have produced 830 Billion tonne since 1989[48]. This provides confidence that coal exploration, extraction, processing, and translocation strategies will likely be very similar in the ORW if this coal land use receives regulatory approval. It also tells us that the types of technologies deployed to help mitigate air, land, and water issues will likely be similar in success or failure to those deployed by Teck Resources in the Elk Valley.

Additional detail on local and regional geology pertaining to coal deposits is extracted from the [Montem's Competent Persons Report][49] ([Appendix E]) that relates to coal projects in the headwaters of the Oldman River Watershed.

Figure 11. Example of a coal seam in the headwaters of the ORW (left). Location of Mist Mountain formation coal seams (shown in green) in southeast BC and southwest Alberta. Modified from Figure e3.2 of AER's *https://static.ags.aer.ca/files/document/Atlas/chapter_33.pdf*

A Synopsis of Current Natural Capital of the Oldman River Watershed Headwaters

To appreciate the potential effects of coal mining on the natural capital of the ORW (both water and biota), it is important to understand the basic physical and biotic elements of this watershed. The following summaries are intended to provide this context.

Geography and Topography

The study area represents the full extent of the Oldman River basin (26,470 km^2) found within southwest Alberta (Figure 2); positioned between 50.68 - 49.00 N latitude and -114.63 and -111.75 W longitude. The study area spans an elevation range from 2,968 m a.s.l. at the continental divide to <800 m a.s.l. in the lower reaches of the basin (Figure 12). A map depicting aspect (Figure 13) for the ORW is shown as it has a major effect on the distribution of various plant communities.

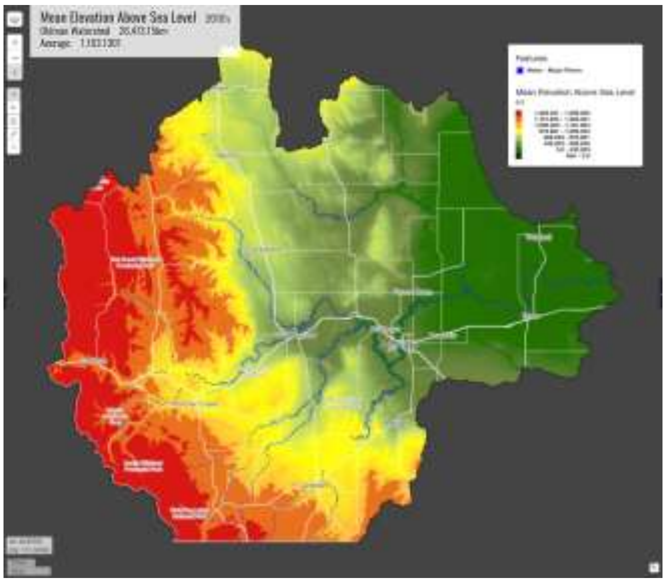

Figure 12. Spatial variation in elevation of the ORW drives regional differences in precipitation and temperature. Source: Alces Online.

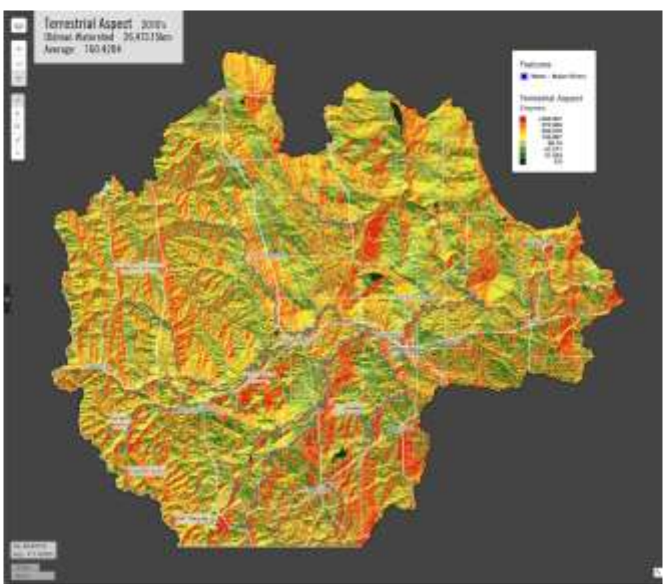

Figure 13. Spatial variation in aspect of the ORW affects solar input and plant community composition. Source: Alces Online.

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Climate and Climate Change

The central issue of this project is water (Figure 14), and hence it is important to understand current and future climatic patterns of the ORW. The climate of the ORW is driven by a combination of strong elevation gradient (Figure 12) and the basin's position in the rain shadow of the main ranges of the Rocky Mountains to the west. Spatial variation in air temperature (Figure 15) and rainfall (Figure 16) are provided below.

Average annual temperature is 3.89 °C, but with a strong seasonal pattern of warm summer and cold winter months. Average annual precipitation is 528.6 mm/yr with a strong positive elevational gradient (Figure 12). The highest elevation portions of the headwaters average 2,000 mm/yr, whereas much of the lower elevation portions receive less than 200 mm/year. Most precipitation falls in the winter months, where it is stored in the form of snowpack, and released as snowmelt during late spring and summer months as streamflow and aquifer recharge. Potential evaporation is negatively related to elevation and exceeds precipitation for most of the lower elevation portions of the basin.

Figure 14. The macro-plumbing of the ORW is one where water is stored in the East Slope mountains as snowpack in the winter, and melts and runs off in spring and early summer. Much of the meltwater is stored in soils, organic deposits or as groundwater in deeper deposits. This meltwater flowing downstream in creeks and rivers is stored in a network of reservoirs, and a portion of the annual meltwater is delivered by canals to downstream agricultural users.

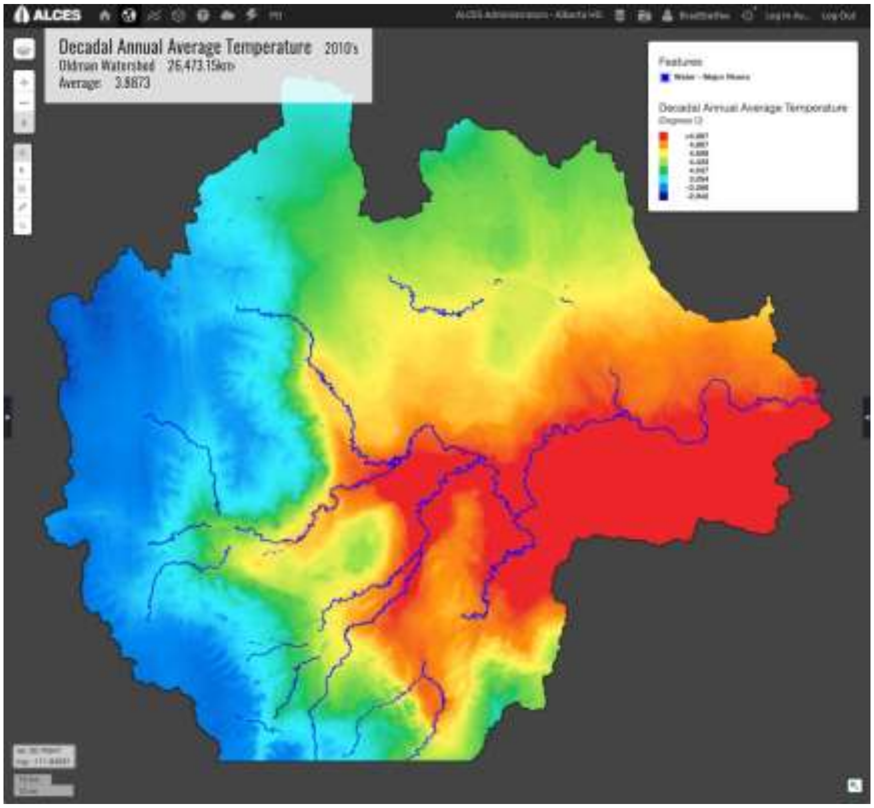


Figure 15. Average annual ambient temperature of the ORW. Source: Alces Online.

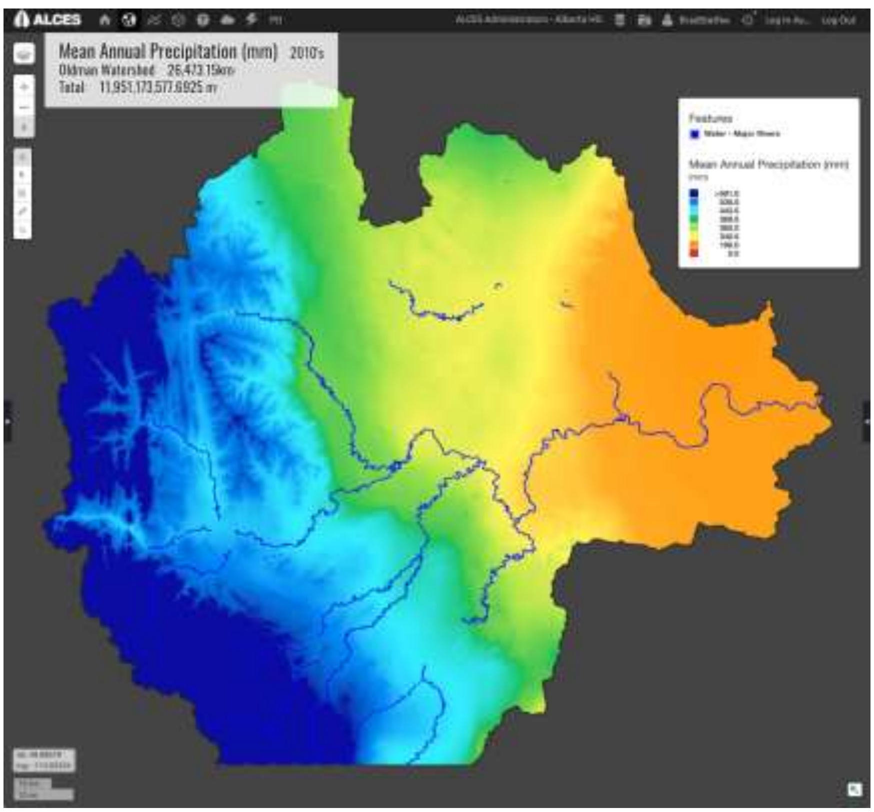


Figure 16. Average annual precipitation (mm) of the ORW. Source: Alces Online.

Hydrology, Sub-watersheds and Delivery of Irrigation Water

Major sub-basins within the Oldman River basin (Figure 142, Appendix I) include (south to north) the St. Mary's River, Waterton River, Crowsnest River, Upper Oldman River, Livingstone River, Willow Creek, and Little Bow River. These tributary rivers flow west to east, eventually join the Oldman River, and at its lower reaches, the basin drains into the South Saskatchewan River at the confluence of the Oldman and Bow rivers. The ORW was stratified into a smaller set of sub-watersheds (HUC10; Figure 143; Appendix I) to facilitate finer scale examination of hydrological processes.

The annual "naturalized" discharge of the Oldman River basin averages 3.267 B m^3/yr but historically varied between ~1.5-7.0 B m^3/yr (Figure 18); ~61.5% of its average annual water flow is allocated for various land uses (primarily irrigation, livestock, municipal, recreation) within the ORW basin. During the past century, the flow and use of water has changed dramatically because of the area and intensity of land use in the lower portions of the ORW. The average flow of the ORW at the mouth of the basin is now ~63% of the naturalized flow prior to the arrival of land uses in the late 1800s. During the past several decades, the recorded average annual flows of the Oldman River (at Lethbridge) are 2.06 B m^3/yr with low flows of 0.282 B m^3/yr being recorded historically. Actual use of allocated surface water is 34.1%[50]. Irrigated agriculture consumes ~83% of total water used in the basin. The flow is highly seasonal (Figure 19) with highest flows occurring in May-July and lowest flows in October-March[50].

The importance of the ORW headwater basins to total streamflow is well documented by the work of Dr. Stefan Kienzle (Figure 20)[55].

Historical records and assessments (Figure 18) indicate that southern Alberta and the Oldman basin periodically experiences extreme droughts (Sauchyn[51,52] , Schindler and Donahue[53], AMEC[54]), such as the one memorialized as the "Dirty 30s" from 1929 to early 1930s that caused a major loss in agricultural productivity.

A network of dams, reservoirs and canals, and complex set of water allocation rules, collectively regulate and distribute water generated from the Oldman basin headwaters to various downstream water license holders (Figure 17). Reservoirs are filled each year during the spring freshet and subsequently release water to downstream license holders during the drier mid and late summer months. Net water flow of the Oldman River, which varies from 1.2 to 4.2 B m^3/yr (Figure 18), provides a critical water source to the people and land-uses of southern Saskatchewan and southern Manitoba. Alberta is legally obligated to provide 50% of the annual flow of the ORW to its downstream neighbours.

Readers wishing to better understand the data, methodology, and allocation rules used by the OSSK (Oldman and South Saskatchewan River Water Model) to regulate water flow in the ORW are directed to the following link: http://www.uleth.ca/research/node/432/.

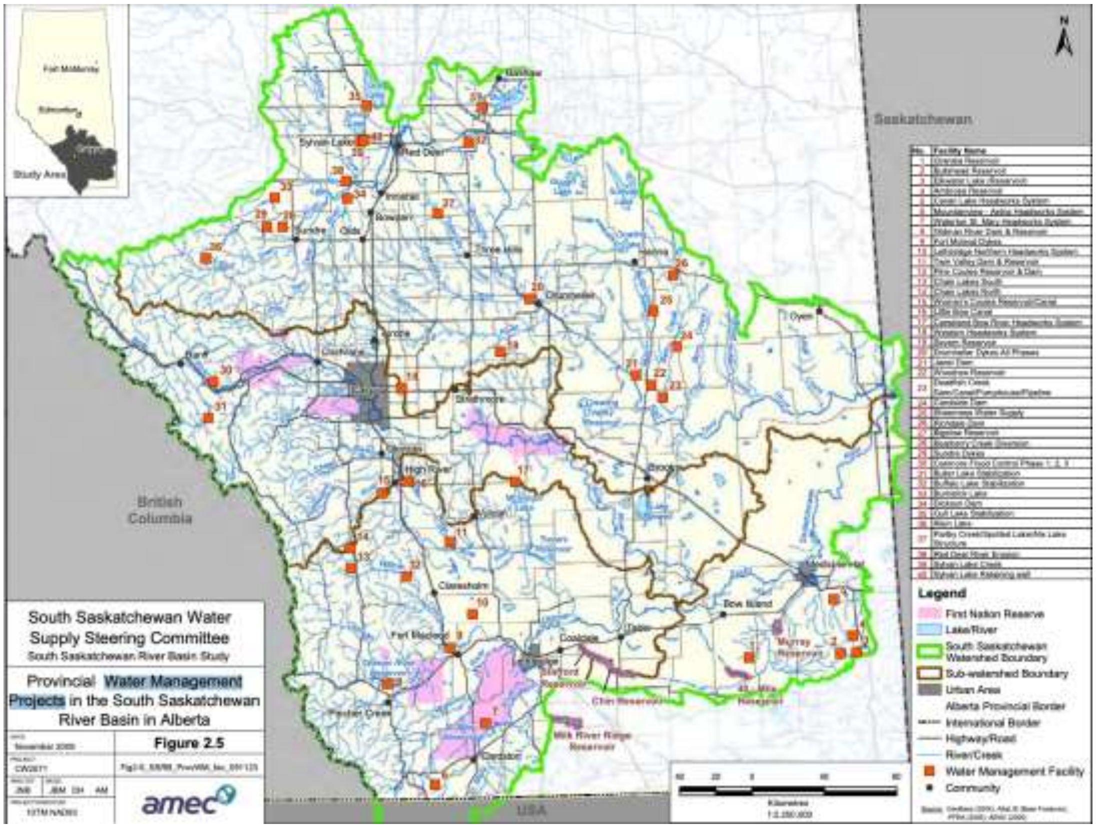


Figure 17. This map illustrates the location of the Oldman River Watershed within the South Saskatchewan Watershed. Source: https://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/irr13053/$FILE/ssrb_main_report.pdf.

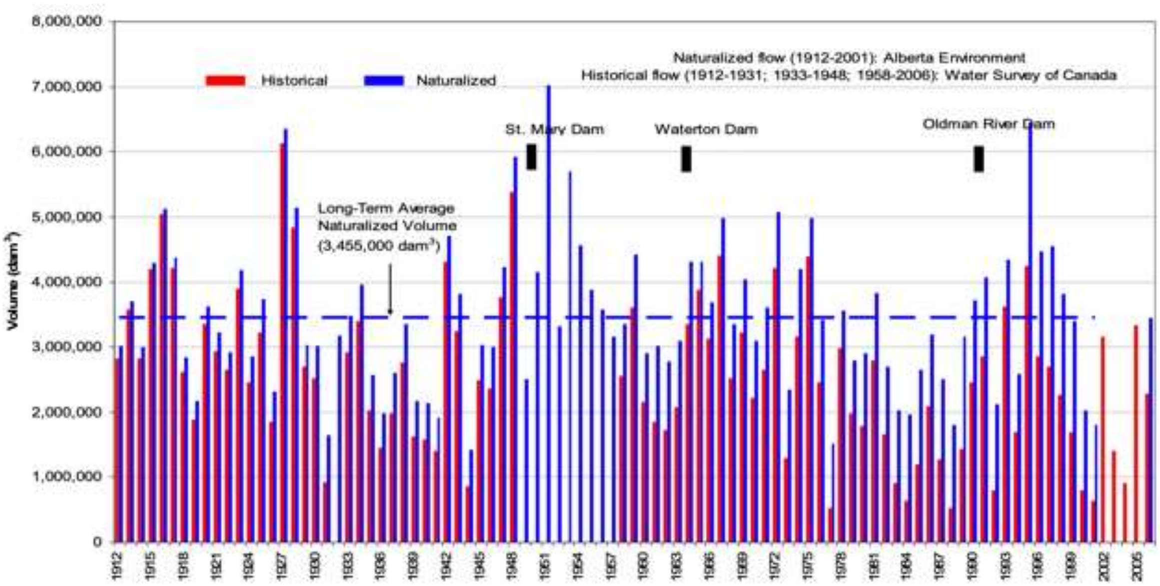


Figure 18. Annual Historical and Naturalized flow volume of the ORW near Lethbridge, Alberta. Source: https://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/irr13053/$FILE/ssrb_main_report.pdf. Naturalized flow values estimate the water flow in the absence of extractive human land uses. Historical records reflect the actual measured flow volumes and hence incorporate the effects of land uses and their water extractions. Note frequently occurring drought years where flow is less ¼ of average.

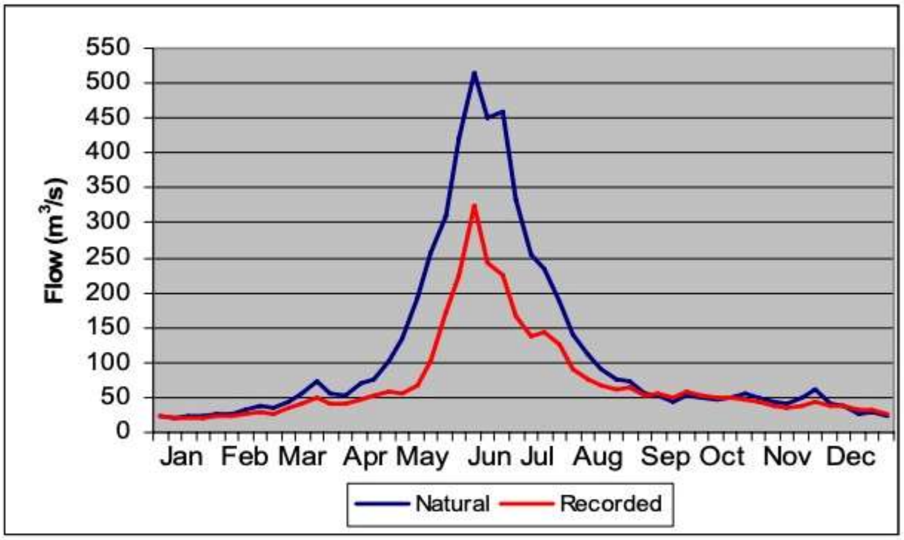


Figure 19. Naturalized and recorded monthly flow of the Oldman River near its mouth (1992 – 2001). Source: https://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/irr13053/$FILE/ssrb_main_report.pdf. The difference between the natural (blue) and recorded (red) flow generally reflects net water extraction in the basin.

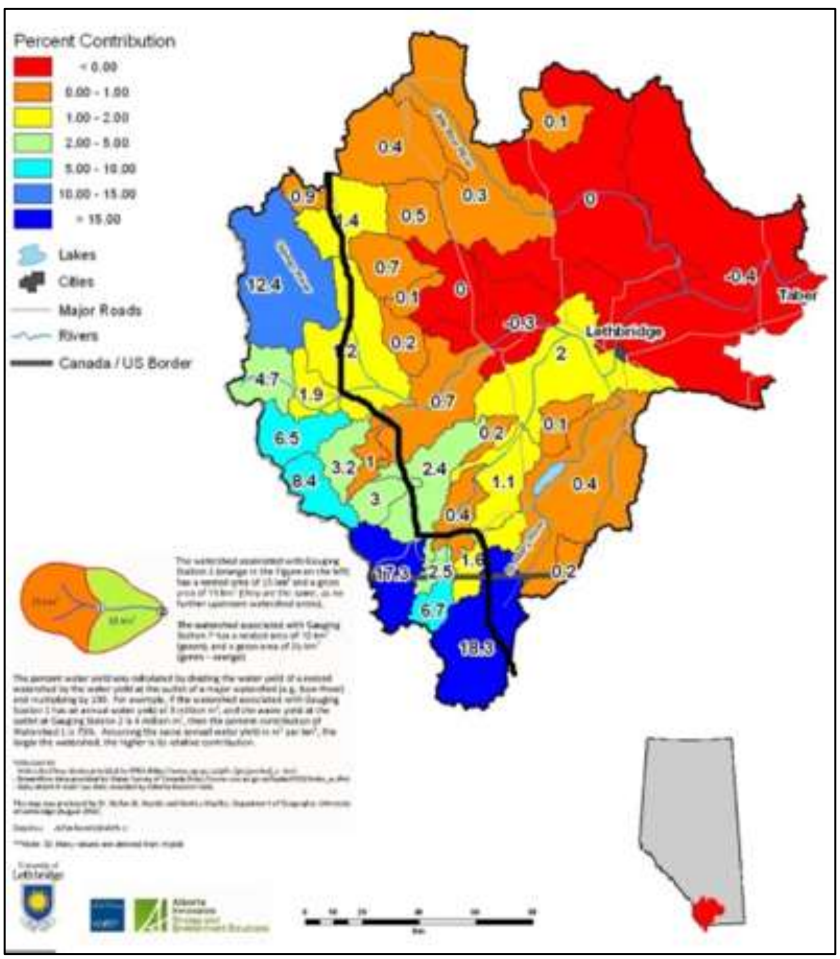


Figure 20. The contributions of sub-watersheds to streamflow (1971-2000) in the Oldman River Watershed. Source: Stefan Kienzle; presented in the State of the Oldman River Watershed; Oldman Watershed Council[55].

A Long History of Recognizing the Primacy of Water

The 2013 Alberta Land Stewardship Act[56] (ALSA) recognizes the critical role that both natural capital and land use play to ensuring social, economic, and environmental sustainability for current and future generations of Albertans. This legislation, and the Alberta Land Use Framework[57] (ALUF) it spawned, also states that sustainable land use decisions must address the issue of landscape prioritization, meaning that planners must identify the key purpose of each landscape and ensure that those key purposes are not eroded by other secondary land-use goals. Repeatedly since the time (1930) that the Government of Canada transferred the resource rights[58] from federal oversight to the Province of Alberta, numerous management initiatives have echoed the important role the East Slopes play for water quantity and quality, and the primacy of this natural capital function to the economic viability of downstream land uses and the integrity of ecosystems.

Getting the Word Out - The Oldman Watershed Council

The Oldman Watershed Council (https://oldmanwatershed.ca/), founded in 2005, is a not-for-profit organization whose mandate is to provide an independent voice for watershed management and health under the Province's Water For Life strategy. This organization has assembled a deep pool of information concerning the ORW, much of which is presented in their 2010 State of the Oldman Watershed reports. The key role of the ORW headwaters in maintaining water and ecosystem function is highlighted in a 2018 report commission by the Southern Alberta Land Trust (SALT). Collectively, these reports are essential reading to understanding the physical, cultural, and biotic context of this watershed as it sets the stage for examining potential implications of coal mining. Specific attention should be given the 2006 report of Byrne et al that describes historical changes in the ORW concerning both water quality and quantity.

Past Assessments

Numerous studies have been completed in the past two decades underscoring the critical natural capital of the ORW headwaters to a range of natural capital metrics. Recent research by the Alces Group (Milligan et al. 2020) and the Office of the Senior Scientist, Government of Alberta[59] , both underscore the important natural capital metrics that occur within the ORW headwaters, and particularly those of the Livingstone FLUZ.

Natural Landscapes

The natural landscapes of the ORW comprise 47% (12,440 km^2) of the watershed, with lower sub-basins often less than 20% natural and the headwater subbasins commonly greater than 85% natural landscape types. This contrast reflects the historical commitment and success that regional conservation initiatives and past provincial governments have had in conserving the natural capital of ORW headwater basins.

Land Use Intensity

Land uses exist across the entirety of ORW but the relative area and intensity declines as one moves further upstream in the ORW (Figure 27). A major landuse of the headwaters is cattle grazing (Figure 35, Figure 38). The ranching community of the East Slopes has been grazing cattle on deeded and crown properties for nearly 150 years. Throughout this time, there has emerged an inter-generational understanding, and practical application, that sustainable grazing on Alberta's foothills demands careful attention to all dynamics that connect cattle to water function. These principles and their applications are widely demonstrated in the "Cows and Fish" initiative[60].

Water Volume and Quality

The vast majority of the ORW water supply originates from headwater basins[61],[62]. Similarly, the water quality of the headwater streams (Figure 42) of these upper sub-watersheds is comparatively high[62]. The significant downstream demand by land uses (municipal, irrigation, livestock, agro-food) for large quantities of high quality water is well documented[96].

Biodiversity

Biodiversity, as exemplified by the mayfly (Figure 21), is a foundational property of ecosystem integrity. In general, the intrinsic capacity for biodiversity is positively related to how much variation in physical (climate, soils, topography) and biotic (plant communities, trophic interactions) features a region possesses, and negatively related to the density of human populations and intensity of their land use[63]. Unsurprisingly, the headwaters of the ORW support comparatively high biodiversity[64], as it is characterized by high variation in physical and biotic

properties and relatively low levels of people and land use intensity[65]. The headwaters of the ORW have been recognized by biologists for several decades as providing critical habitat for innumerable species whose habitat elsewhere in Alberta has become reduced or fragmented by various overlapping land uses[66]. Examples of species that the Government of Alberta categorizes as "at risk, threatened, or endangered" provincially but still maintain populations within the ORW headwaters include grizzly bear, Westslope cutthroat trout, bull trout, harlequin duck, lake sturgeon, limber pine, long-billed curlew, long-toed salamander, leopard frog, prairie falcon, rocky mountain sculpin, Sprague's pipit, western blue flag, western grebe, white-barked pine, ferruginous hawk, and bull trout[67]. In addition to their existential value, the conservation of these species, and the habitat they depend on, contribute meaningfully to the eco-tourism sector that is growing in the ORW[68].

The extent to which the "at risk" species listed above persist in the ORW headwaters will be determined by how current and future land-uses alter the area, quality, and continuity of habitat and the physical properties of these regions. Of the species listed above, populations or habitat use of several high-profile species have been shown to be affected by coal mining activities in Alberta and the Elk Valley of BC. These include bighorn sheep[69],[70], grizzly bear[71,72], and Westslope cutthroat trout[73,74,75].

Addressing Endangered Species

Of the species currently listed as "threatened", the Westslope cutthroat trout has been selected to highlight some of the concerns that additional industrial development in the ORW headwaters may cause.

Figure 21. The aquatic invertebrate community, exemplified above with a mayfly, are highly sensitive to coal emissions such as selenium. The innumerable invertebrate species that comprise the benthos community are critical for many aspect of stream ecology and water quality, and are an important food source for such endangered species as WSCT. Photo Credit: Bob Costa.

Westslope Cutthroat Trout

Westslope cutthroat trout (WSCT; Figure 22), the only subspecies of cutthroat trout native in Alberta and an important game fish, have occupied the ORW since glacial ice sheets retreated[76,77]. Prior to 1900, WSCT were estimated to be distributed across most of the ORW headwater sub-basins[78]. During the past several decades, land-use induced changes in water quality and quantity, habitat dis-continuity, introduction of exotic species, genetic introgression by non-native cutthroat trout subspecies, over-fishing, and climate change, have in combination led to a significant retraction in total distribution and abundance in the study area (Figure 23)[79]. Today, WSCT occupy <10% of their historical range, and were designated as "Threatened" by the Minister of Sustainable Resource Development in 2009 under Alberta's Wildlife Act.

In recent decades, WSCT have received considerable scientific attention as conservation agencies and organizations work to halt declines in populations and range and seek answers to how to reclaim and recover lost habitat and populations. The specific causes of habitat and population reductions are complex, multi-variate, differ geographically, and are the result of the cumulative effects of many factors[80]. In Alberta, published research on WSCT began with R.B. Miller[81]; recent research initiatives have been completed by Mayhood[82] and Cleator et al.[83], [84]. In the Elk River drainages in southeast BC, WSCT are studied closely because of concern about selenium toxicity. These WSCT populations have experienced significant declines in abundance[85], and elevated rates of morphological and reproductive impairment[86] caused by very high selenium concentrations in the Elk Valley system downstream of the Teck coal mines[85].

Canada's Westslope cutthroat trout recovery plan identifies those headwater basins in the Upper Oldman watershed that are considered critical to conservation of remaining WSCT populations and habitat. The prospective coal mines are spatially overlapped with several of these "critical" watersheds including those of Daisy Creek, Spoon Creek, Many Stick Creek, Speer Creek, Honeymoon Creek, Isolation Creek, and South Hidden Creek (Figure 24). If these prospective mines do move forward, WSCT scientists are concerned that habitat loss and selenium toxicity will cause significant adverse effects and complicate conservation efforts of this threatened fish species.

Figure 22. Westslope cutthroat trout are a popular game fish in the ORW, whose distribution, habitat and populations has been significantly reduced during the past several decades. Source: CPAWS, Southern Alberta. The image on the right shows a rainbow trout with a missing gill plate. Photo Credit: Bob Costa.

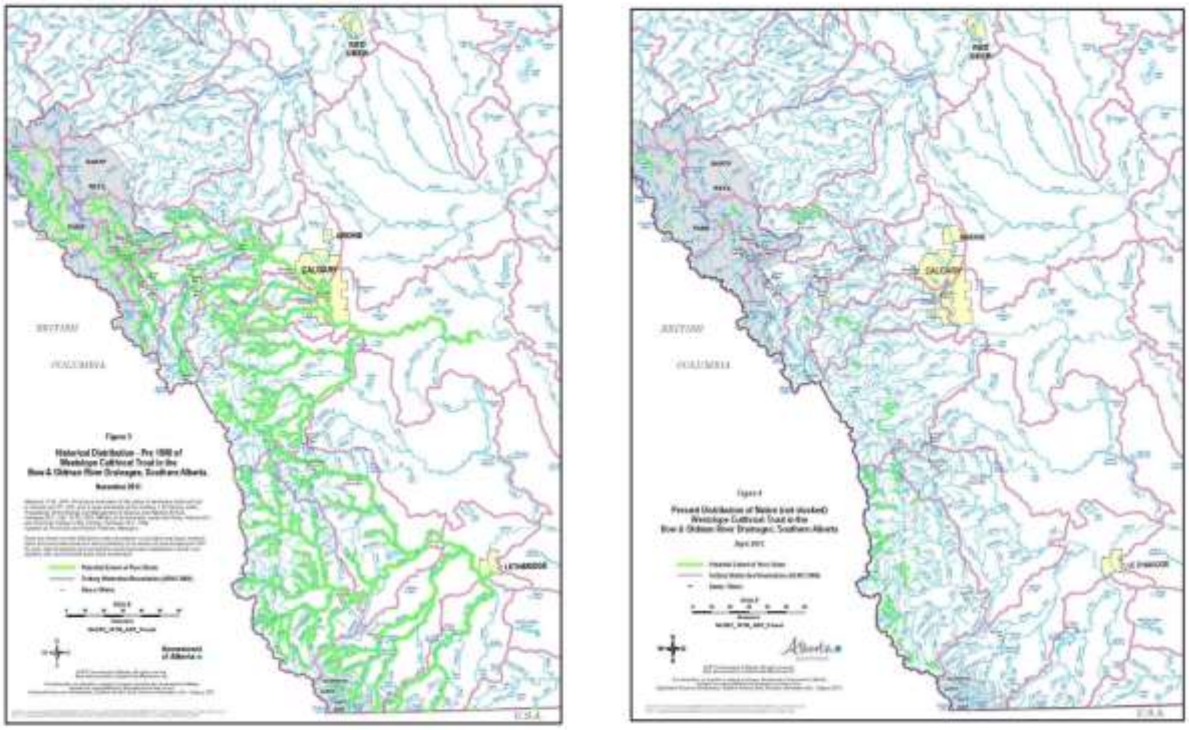


Figure 23. Historical (left) and current (right) distribution of Westslope cutthroat trout in the Bow and Oldman River drainages, southern Alberta. Source: https://open.alberta.ca/dataset/c9ab0297-c99a-4478-b9e5-ff8d7b9d2c03/resource/ab4527e8-0643-47ec-842a-efd79a6221b5/download/6246341-2013-alberta-Westslope-cutthroat-trout-recovery-plan.pdf

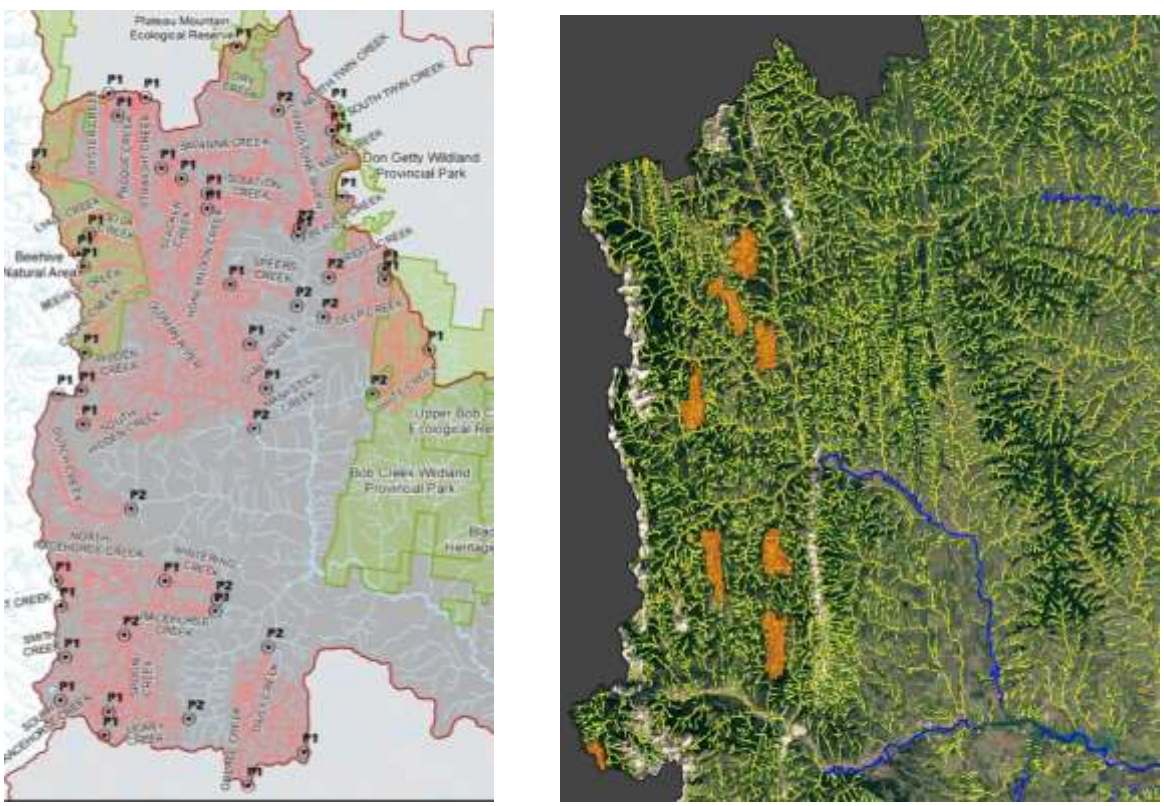


Figure 24. Comparison of critical WSCT watersheds in the Upper Oldman River watershed identified by the WSCT recovery plan (left) and the distribution of the prospective coal mines found in the headwaters of the ORW (right). Note that most of the proposed mine sites overlap with headwater streams critical to remaining populations of WSCT.

Landscape Integrity

Much of the headwaters of the ORW has been designated as "environmentally significant areas" at regional, national and international scales[87]. The headwaters of the ORW remain largely intact in terms of their area of natural plant communities (Figure 26, Figure 27), and currently have minimal levels of water demand – primarily those of grazing cattle on private lands and public lease lands. It is the combination of high levels of precipitation and natural plant communities, and low water demand, that contribute to the large volumes of high quality water that flow from these headwaters. In contrast, the lower elevations of the ORW are heavily transformed by various land uses (irrigated crops, non-irrigated crops, livestock infrastructure, residential; Figure 25) and have high levels of water demand. The network of downstream land uses are completely reliant on the water supplies (quality/quantity) of the headwaters, which in turn owe their existence to the climate and landscape integrity in the headwater basins. The 8 prospective coal mines are found within headwater sub-watersheds with the highest remaining integrity values (Figure 25).

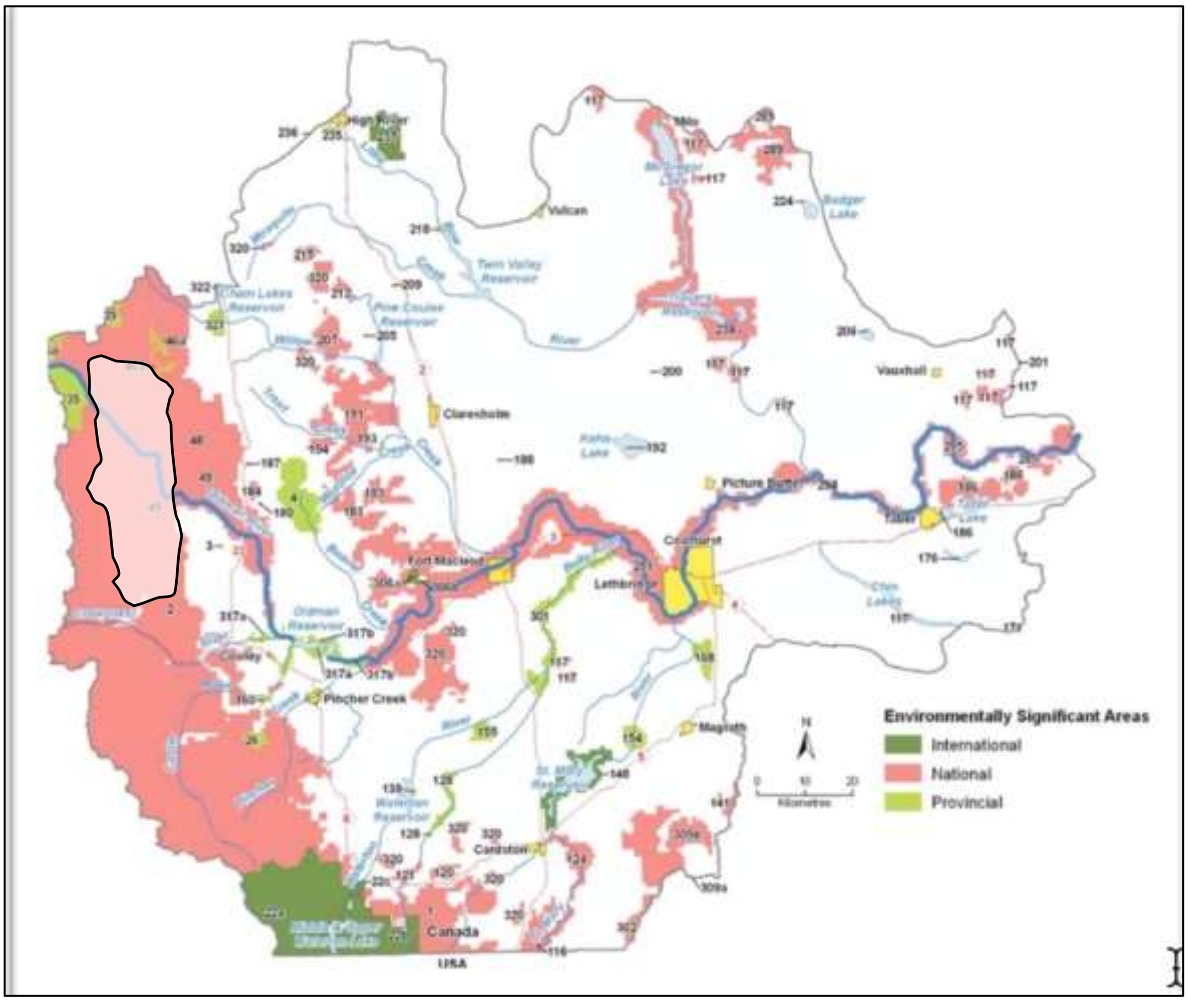


Figure 25. Environmentally significant areas of provincial, national and international significance in the ORW. Source: Oldman Watershed Council. The generalized distribution of existing coal leases in Category 2 north of the Crowsnest Pass is illustrated with black boundary and light white translucent shading. These coal leases occur in areas defined as "environmentally significant" at a National scale.

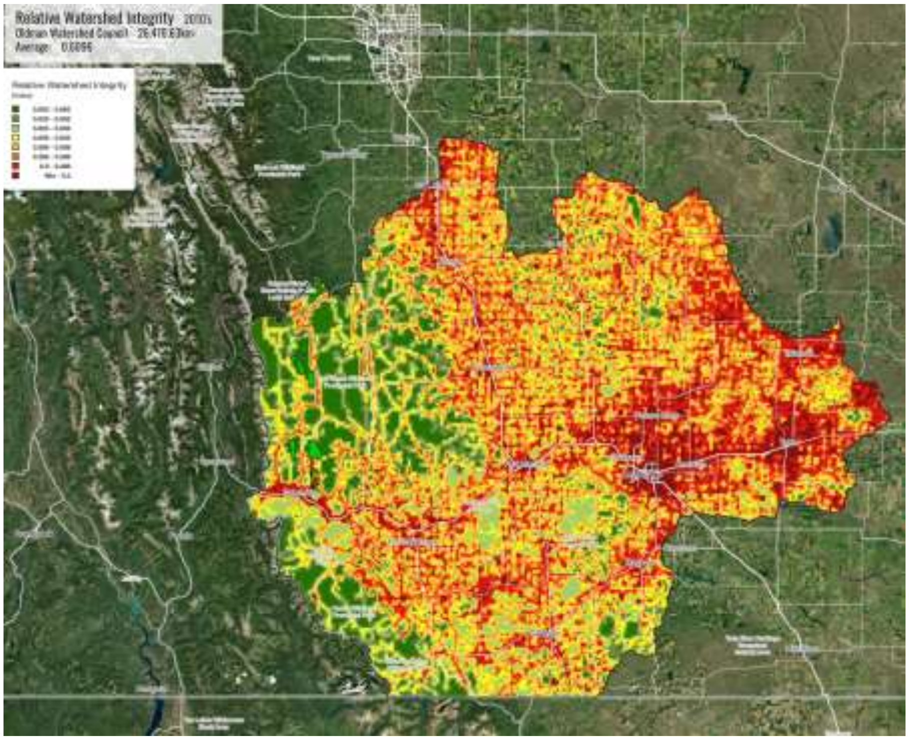


Figure 26. Spatial variation in watershed integrity that incorporates precipitation, natural areas, and linear features. Green colors reflect high watershed integrity and red values reflect low integrity values. The location of prospective headwater coal mines shown as light green polygons with black borders. Source: Alces Online.

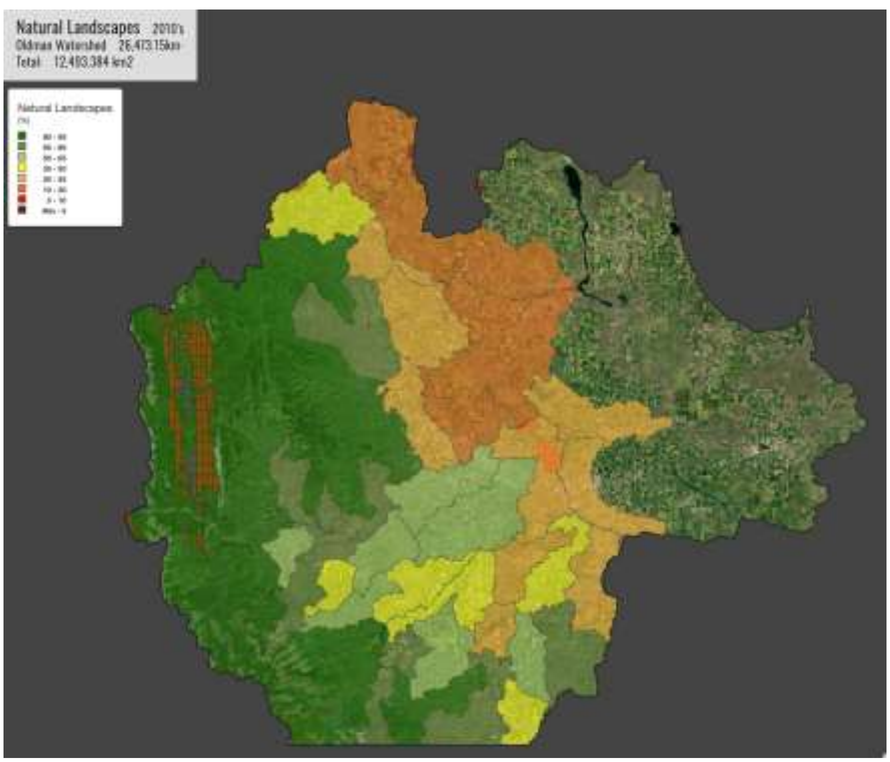


Figure 27. Left. Relative fraction of "natural landscape types" in the ORW. Watersheds that are dark green have highest levels of natural areas and those that are red or clear have low levels of natural landscape types. Also included are existing coal agreements (shown in red hatches). The lower portions of the ORW do not visualize as sub-watersheds as they do not contribute net flow of water.

Current Demand for Water in the ORW

Land Uses and Water Demand

To understand the concerns of ORW residents about water security in regard to coal mining in their headwater basins, one must appreciate where the ORW water comes from (see the Hydrology, Sub-watersheds and Delivery of Irrigation Water section) and historical[88], current, and projected demand for water from existing land-uses. Excellent overviews of the water dynamics (supply and demand) of the ORW are provided by the Oldman Watershed Council and summaries provided by South Saskatchewan River Basin in Alberta: Water Supply Study[89]. At the scale of the ORW basin, the average annual flow is 3.2 B m^3/yr, the current allocation is ~2.0 B m^3/yr and the actual use is ~1.3 B m^3/yr[90]. These "average" values are instructive, but it is the inter-annual variation in water flow that is critical. Whereas inter-annual variation in demand does not change drastically, the supply side (flow) can vary significantly depending on year-to-year variation in precipitation. According to the analyses completed by AMEC for the South Saskatchewan River Basin in Alberta: Water Supply Study the anticipated growth in area and water demand between 2006 and 2030 is significant for each of municipal, cattle, and the irrigation sectors. In sum, actual water use is expected to increase by a further 46% between 2006 and 2030[54]. With each passing decade, water demand continues to increase, as does concerns about water supply scarcity. As shown by Chernos et al (2021), water supply for the ORW is likely to experience significant variation, including periods of significant drought. As ongoing climate change patterns increase the frequency and magnitude of droughts in the ORW, so will the intensity of water shortages and the need to rationalize an increasing water demand with a progressive decline in water availability.

Quick Overview of Current Land Uses and their Water Requirements

The current land use footprint within the 2.65 M ha ORW study area is 1.2 M ha, comprised of 1.05 M ha of crop, 77,869 ha of pastureland, 32,592 ha of residential, 27,860 ha of transportation, 8,350 ha of feedlots, 3,783 ha of recreation, and 2,823 ha of industrial features (Alces Online, 2018). Each of these land uses owes its economic prosperity to adequate volumes of high quality water provided by the headwaters of this basin. A total of 29,700 ha of reservoirs and delivery canals have been constructed in the ORW to provision water to land uses, primarily to the 318,463 ha of irrigated land.

Human Population and its Residences

The current ORW (2022) population (Figure 30) is estimated at 238,000 residents (based on a 2006 population of 207,000 that has grown at an annual rate of 0.8%/yr). Residents consume ~64.6 M m^3 of water annually (Figure 28) for a range of domestic needs (direct water consumption, washing, showers, lawn watering, …). This averages about 0.742 m^3/person/day[91],[92]. Almost all drinking water for this population originates in the headwaters of the ORW. During the next 50 years, this population is expected to grow to 355,000 people whose domestic water demand will grow to ~96 M m^3/yr. In comparison to other regions in Alberta, the ORW currently enjoys relatively low water treatment costs[93] (Figure 29). This reflects the high quality of surface water in the Oldman River provided by the upper reaches of the basin. Any reduction in water quality (from increasing concentrations of nutrients, sediments, heavy metals, Selenium) would be expected to increase these treatment costs significantly.

The residential footprint (32,592 ha; 325.9 km^2) of the ORW consists of cities, towns, First Nation Reserves (Figure 31), hamlets, acreages and agricultural residences. Based on Alces historical backcast simulations, the residential footprint has been growing at a rate of 1.5-2.0%/yr (Alces Online). There are several dozen communities within the study area, with Lethbridge, Pincher Creek and Fort McLeod being the largest (Figure 2, Figure 31).

Figure 28. Domestic water consumption is the highest priority in the ORW and is expected to nearly double in the next 50 years.

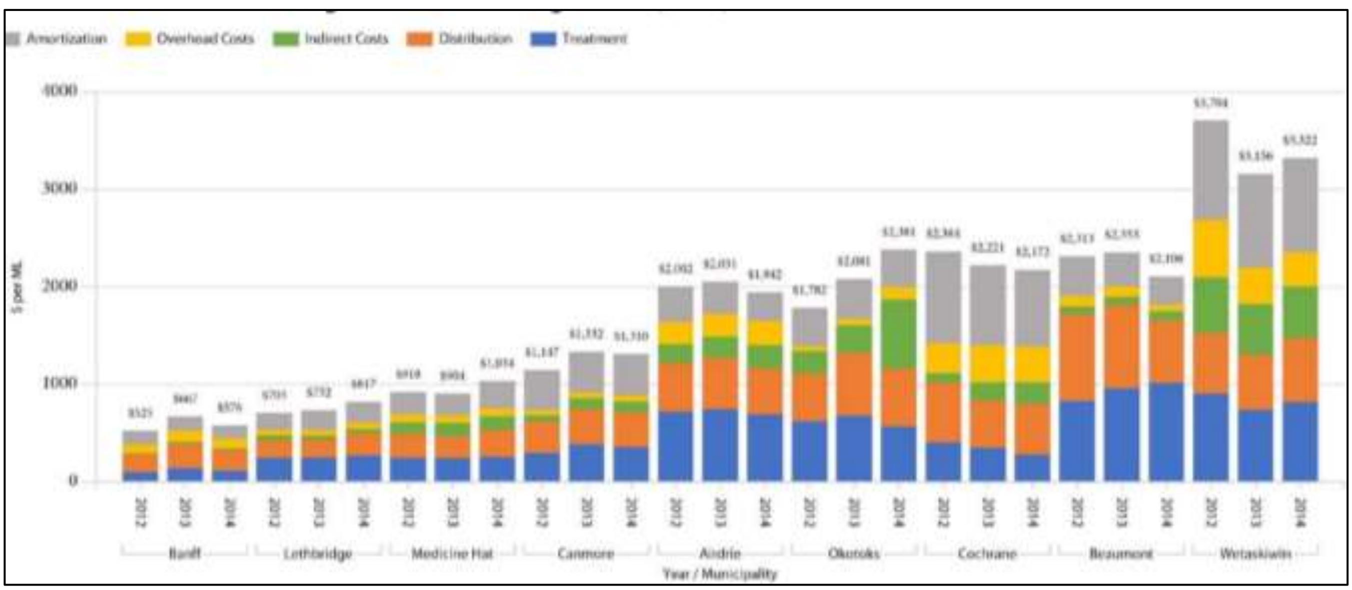


Figure 29. In comparison to other regions in Alberta, the major communities of the ORW currently enjoy relatively low water purchase costs. This reflects the high quality of drinking water currently provided by the source waters in the upper reaches of the basin. Any reduction in water quality (nutrients, sediments, heavy metals, Se, would be expected to increase these costs. Source: https://banff.ca/DocumentCenter/View/4696/Benchmarking-Water-Report?bidId=.

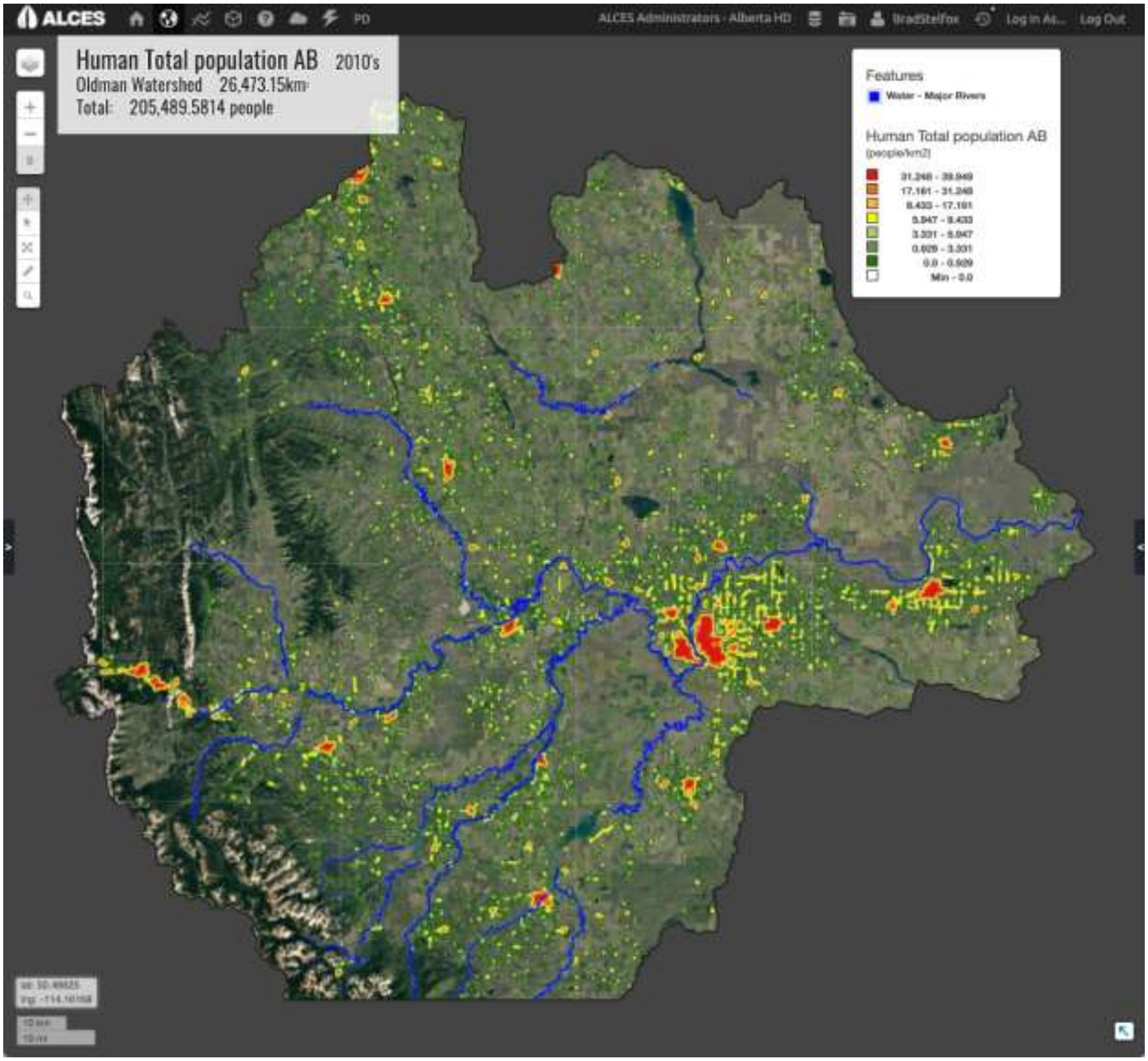


Figure 30. The distribution of the human population (2016) in urban and rural settings. Source: Alces Online and Statistics Canada. This population, and the different land uses that support it, are dependent on large quantities of high quality water that is sourced from the headwaters of the ORW.

First Nations

The Oldman River Watershed is within Treaty 7 and represents the homelands for the Aputosi Pii'kani people of the Blackfoot Confederation[94]. The First Nation reserves (Figure 31) in the ORW include the Piikani Reserve (423.6 km^2), the Peigan Timber Limit (29.6 km^2), the Blood Reserve (1,391.5 km^2), and the Blood Timber Limit (19.2 km^2).

Of the Reserves, the Piikani Reserve will be the most directly affected by coal mining as it is bisected by the Oldman River and is directly downstream from prospective coal mines examined in this report. Irrigated crops are an important land use in the Blood Reserve (Figure 32), and these crops depend on adequate water quality and quantity provided by the ORW headwaters. The history and importance of water rights to the First Nation peoples of Alberta is discussed by Passelac-Ross and Smith (2010)[95].

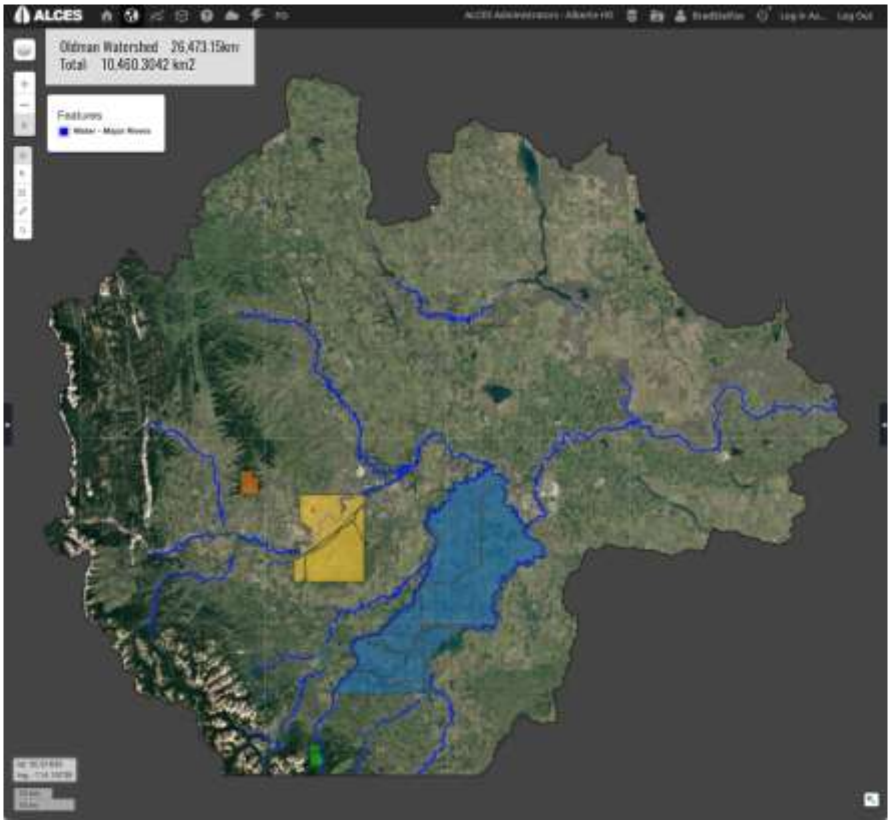


Figure 31. First Nation Reserves within the ORW. Source: Alces Online and ABMI 2019.

Figure 32. Irrigated cropping is one of several land uses on the Blood Reserve southwest of Lethbridge. Source: Alces Online and ABMI 2019.

Crops

The total cropland mosaic of ORW (1,046,000 ha; 10,460 km^2) consists of both irrigated (318,463 ha; 3,184.6 km^2 [96]) and dryland (~727,537 ha) crops. For the past several decades, irrigated crops (Figure 33) have been the single largest consumer of surface water in the ORW – currently at a withdrawal rate of 979,157,000 m^3/yr (net water use of 826,177,000 m^3/yr[96]. This region produces a diversity of crop types marketed locally, provincially, nationally, and internationally. To ensure a reliable water supply, a series of reservoirs (Figure 33) and connected canals have been constructed over the past century. Management of water supply and demand for irrigation purposes is administered by Irrigation Districts[97] (Figure 34). Recent basin management plans emphasize the growth of the irrigation landbase and the future elevated water demands of this sector[96]. As the frequency and magnitude of droughts caused by climate change afflict this basin, supply/demand constraints will become increasingly apparent, and the basin will need to rationalize priorities of which land uses receive water and which do not. The addition of water use by coal mining in the headwaters of this basin will exacerbate this dynamic.

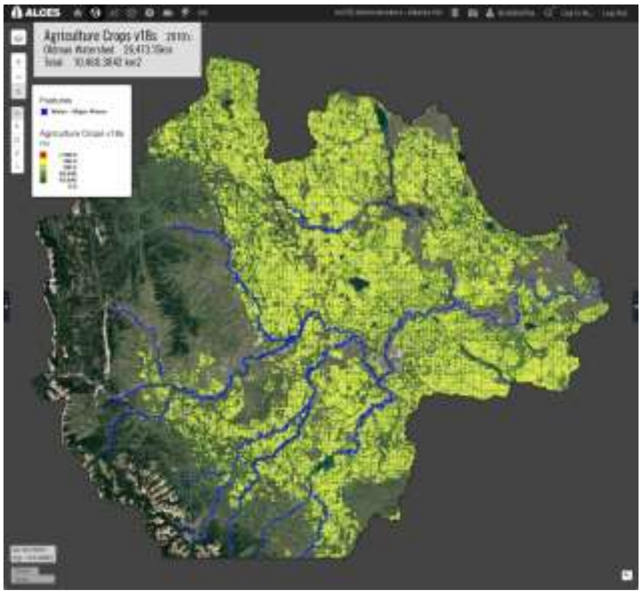


Figure 33. Total croplands (1,046000 ha) within the ORW. Source: Alces Online and ABMI 2019.

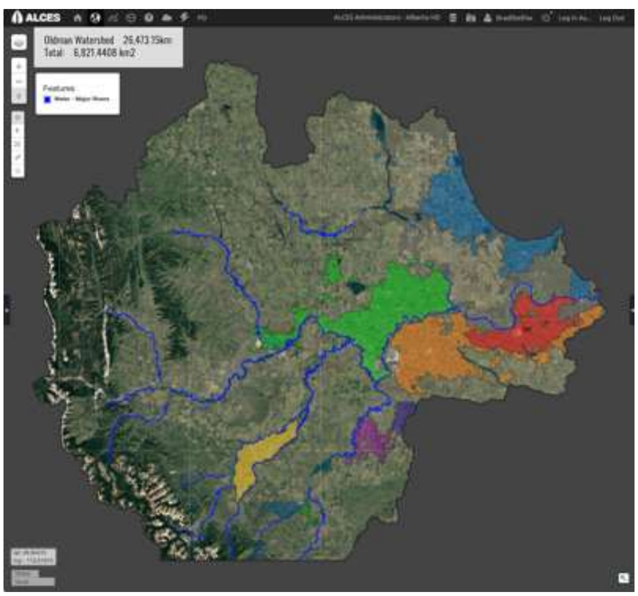


Figure 34. Irrigation Districts of the ORW, showing major river systems. Source: Alces Online.

Livestock

The cattle population of the ORW is estimated at 1.0-1.2 million animal units (AU), whose "averaged" life-cycle distribution (Figure 35) is reflected seasonally in pastureland (Figure 36), feedlots (Figure 37), and headwater crown grazing permits (Figure 38). With an average standing biomass of 400 kg/AU, and an average water consumption of 41 liters/AU/day[98], the current standing biomass (~440 M kg) of cattle requires ~16.5-18.0 M m^3 of water/yr. The majority of the water used for cattle in the ORW originates in the headwater basins.

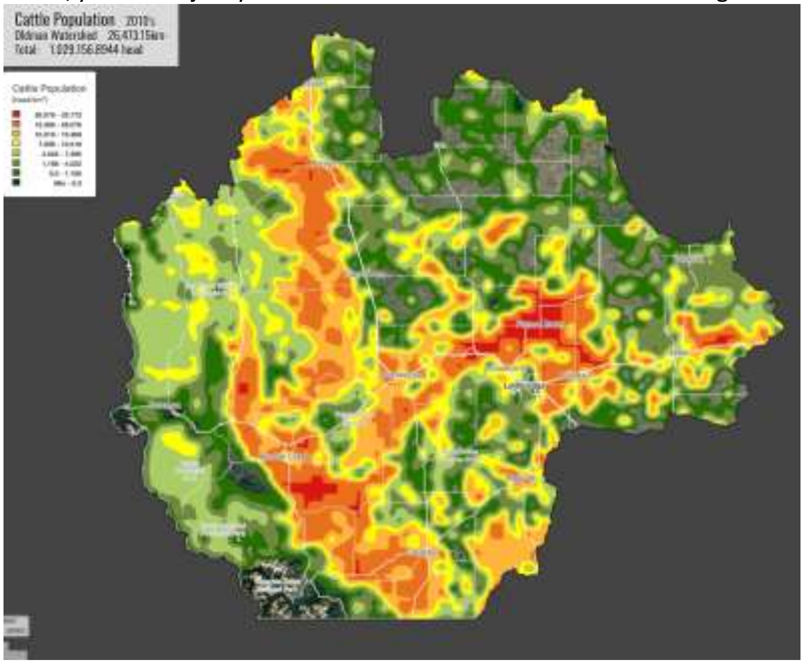


Figure 35. Generalized spatial distribution of cattle in the ORW. Source: Alces Online.

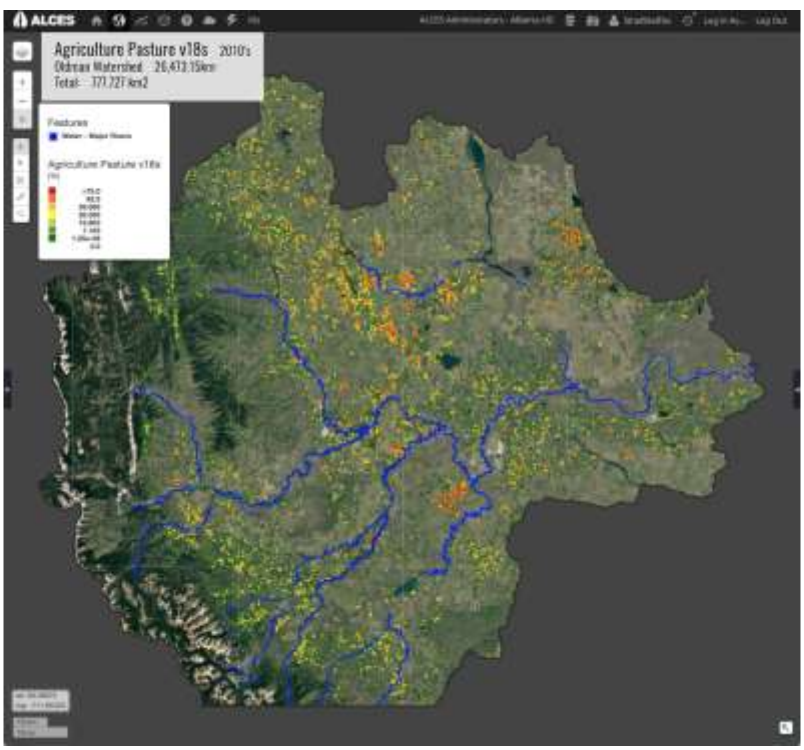


Figure 36. Pasturelands (~77,773 ha) within the ORW. Source: Alces Online and ABMI 2019.

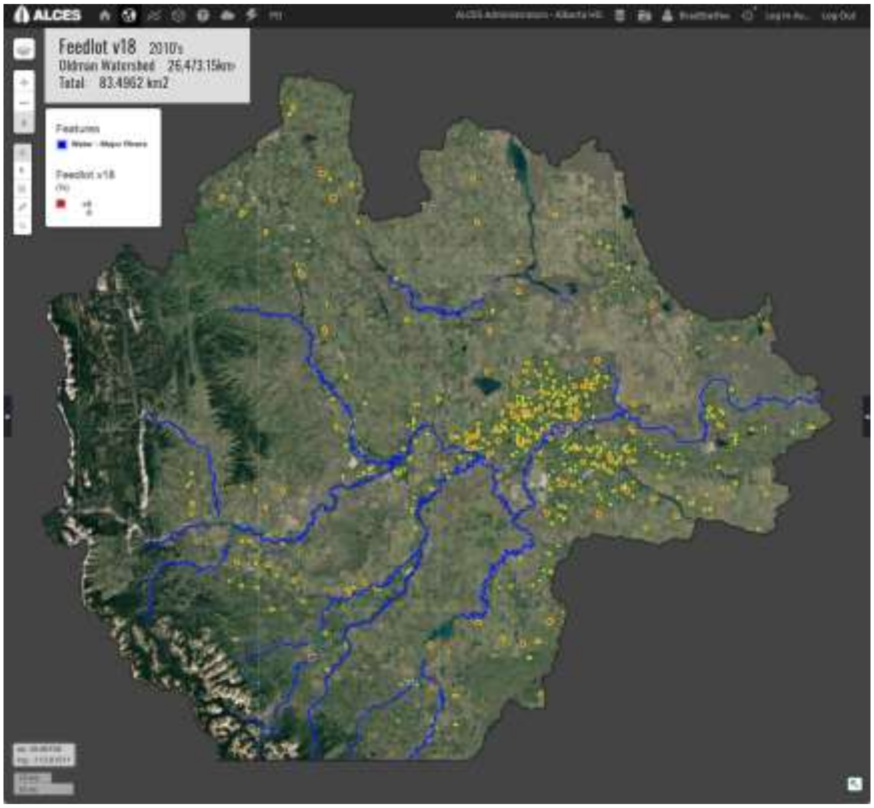


Figure 37. Livestock feedlots within the ORW. Source: Alces Online and ABMI 2019.

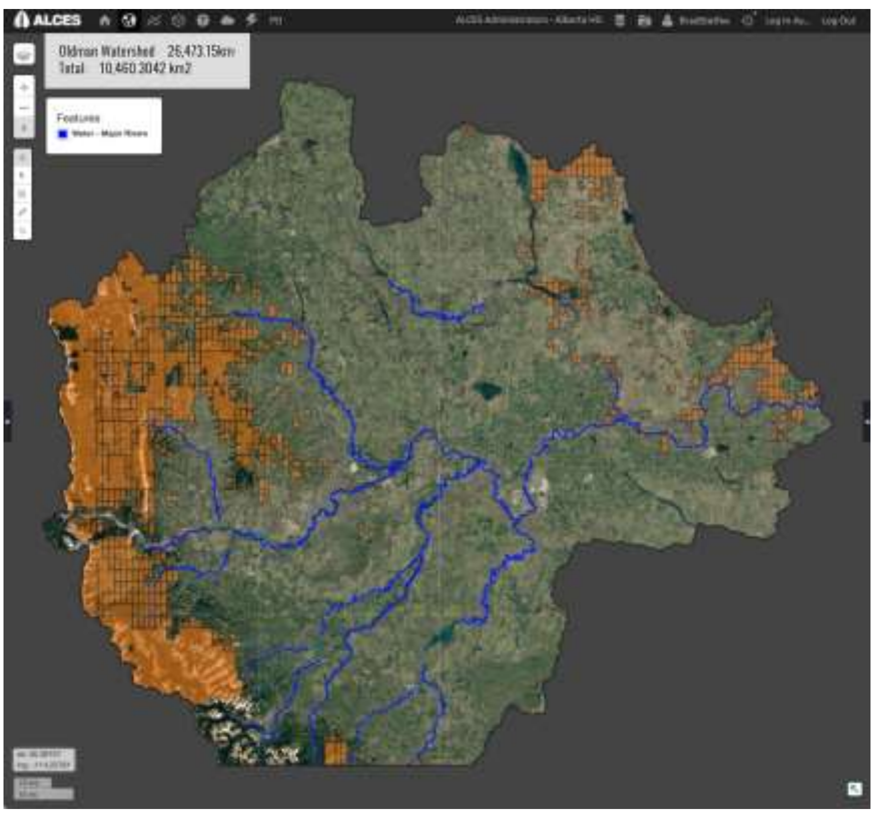


Figure 38. Crown Grazing Permits, ORW. Source: Alces Online.

Protected Areas

The network of protected areas within the ORW (Figure 39) plays a critical role in ensuring adequate water supply and quality to all downstream land-uses in the basin. It is widely understood by landscape ecologists[99],[100] that maintaining natural plant communities in a functional state in headwater basins is the single most important consideration to proper hydrological function. Recent surveys by CPAWS indicates that 70% of Albertans approve of an expansion in the protected areas of Alberta's East Slopes[101].

A key element of local (SALTS, Livingstone Landowners Group), provincial (AWA), national (CPAWS, Nature Conservancy of Canada), and international (Y2Y) organizations is the conservation of natural habitat that allows for the retention and continuity of ecosystem dynamics and endangered species in the headwaters of southern Alberta. Elements of this protected area matrix are illustrated below (Figure 39), and demonstrate a significant discontinuity in designated protected area immediately north of the Crowsnest Pass. It is in this region that ~100 km^2 of coal mines are proposed by investors, and examined within this report. If coal mining were to proceed in this region, a significant loss of landscape continuity would occur in the ORW headwaters and this loss would have larger regional implications to conservation of endangered species such as WSCT, bull trout, and grizzly bear.

The spatial extent of the Y2Y initiative reminds us of the challenges of maintaining adequate continuity of natural landscapes along the Rocky Mountains (Figure 40; left image). One of the current "missing links" occurs in the headwaters of the ORW (Figure 40; right image), where north of the Crowsnest Pass there is a gap in terms of designated protected areas. Although this region has provided ecological connectivity historically, this ecosystem service will be lost if it is transformed by regional industrial land uses.

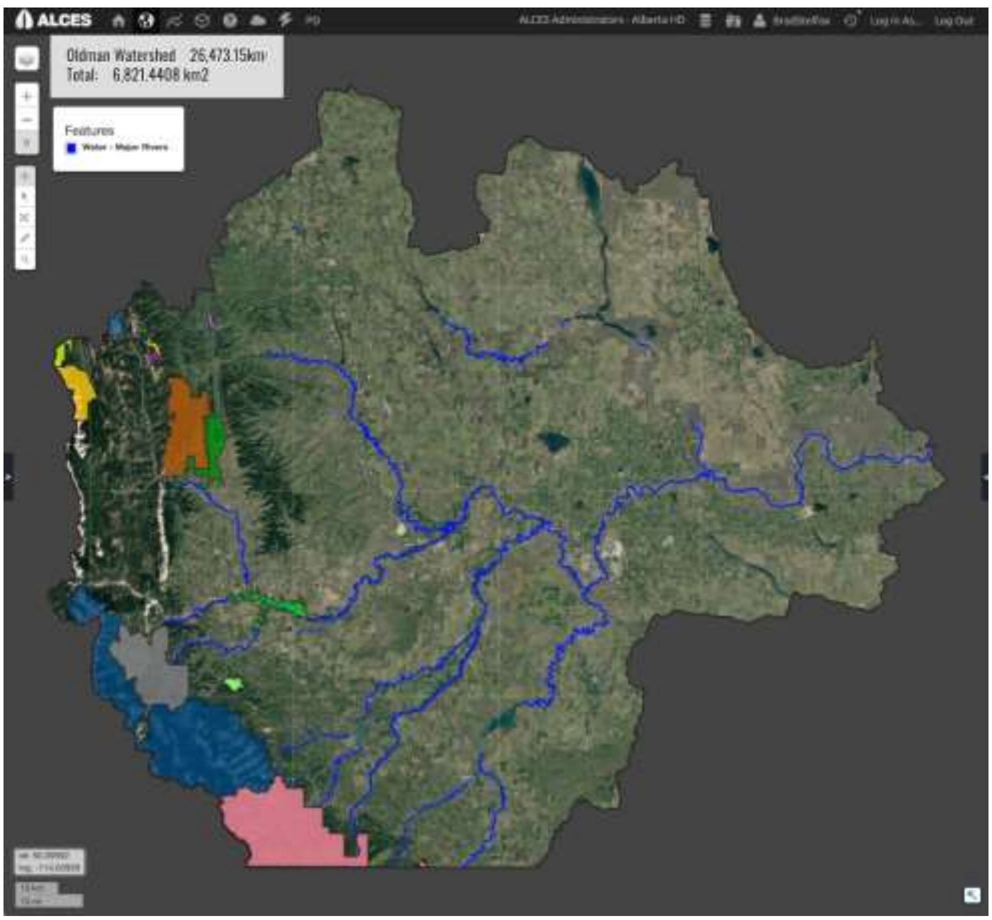


Figure 39. Current Protected Areas Network of the ORW. Source: Alces Online. There exists a continuous network of protected areas in the headwater of the ORW south of the Crowsnest Pass. This "designated" protected areas network is interrupted north of the Pass. Historically, the natural state of these headwater basins ensured connectivity, but this ecosystem service would be eroded by any large industrial activity.

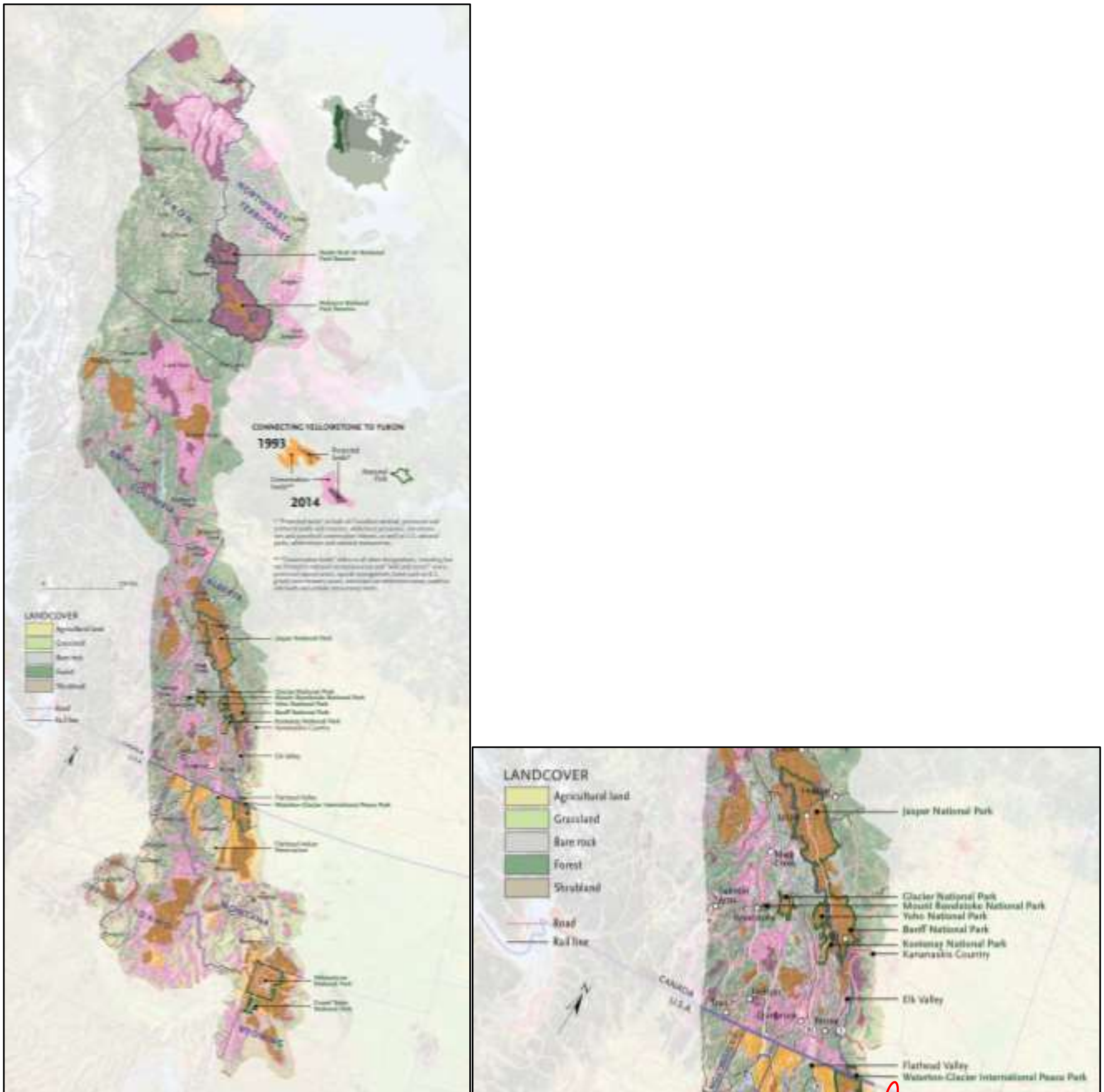


Figure 40. A map (left) prepared by [Y2Y](#) (Yellowstone to Yukon) illustrating the geographic extent of their conservation initiative and the distribution of protected lands and conservation lands in the Y2Y corridor. Areas that are pinkish represent lands protected as of 2014 and those that are yellowish/orange-ish are those that existed in 1993. The map on the right highlights southwest Alberta and southeast BC. Note the absence of designated conservation and protected area in the headwaters of the ORW north of the Crowsnest Pass (Oval with red boundary). This region has provided high spatial continuity to ecosystem dynamics in the past because of the relative absence of intensive land use. This functionality would be lost in the event of a large regional coal mining development.

The ORW lies in the rain-shadow of the Rocky Mountains, and hence precipitation is lower than exists on the BC side. The majority of precipitation it receives occurs in its headwater basins, and this water is critical to all downstream land uses in the ORW. The distribution of total water demand in the ORW is estimated in Figure 41. The current allocation and use rate of water in the ORW is relatively high (hence it has been defined as a closed basin), and arguably quite high relative to maintenance of instream flow requirements. This water supply/demand imbalance is particularly concerning during late summer and early winter and particularly during years of low precipitation and flow. As frequency and magnitude of droughts increase in a future ORW, there will emerge a need to revisit the math that balances water supply and demand.

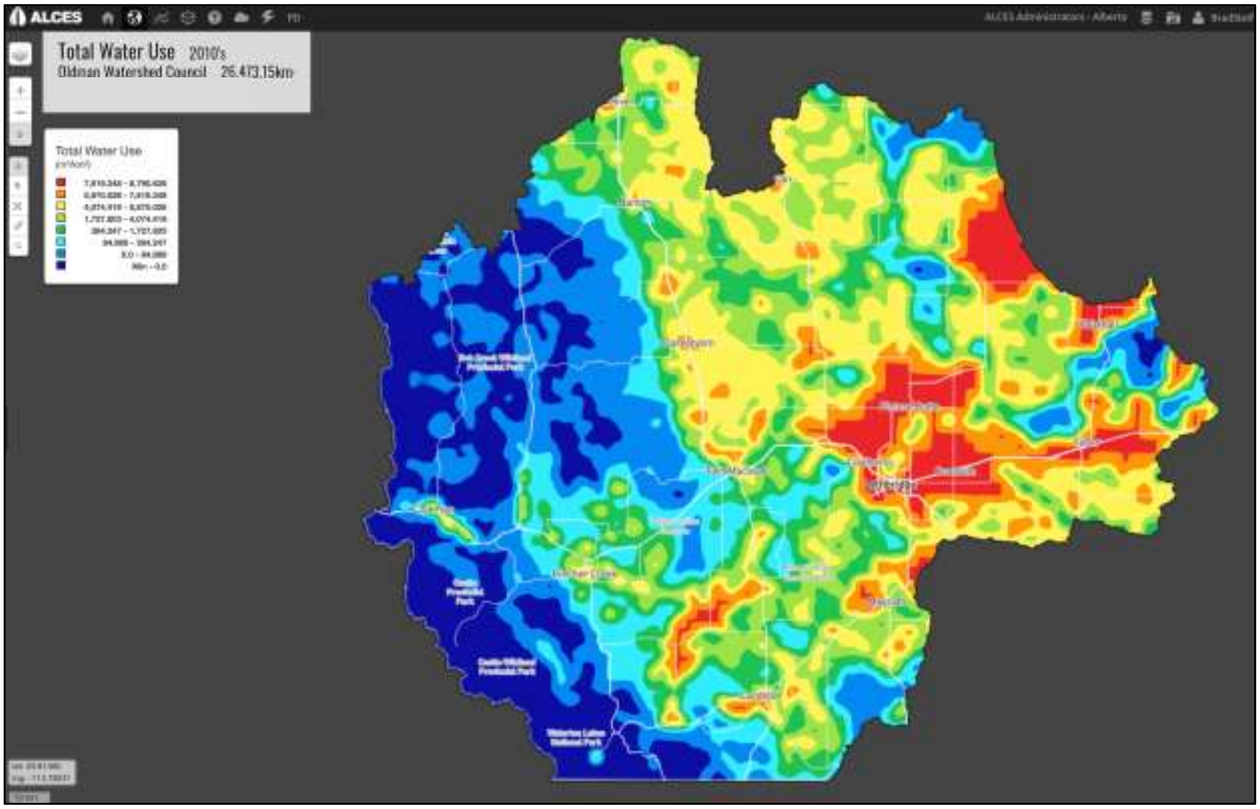


Figure 41. Spatial variation in the use of water by all land uses. Source: Alces Online.

Aquatic Ecosystem Dynamics and Their Water Requirements

All stakeholders involved in the discussion of coal mining in Alberta's East Slopes seem to echo the importance of water and aquatic environments, and also their commitment to maintain this critical element of natural capital. And whereas there appears to be good knowledge regarding the spatial and temporal water demands of all land use sectors (coal, irrigation, municipal, livestock, recreation, …), there appears to be no robust analyses that focus on the amount and timing of water required to maintain acceptable aquatic ecosystems in Alberta's East Slopes. Rather, there appears to be a recognition that some of the water, nominally 20%, should stay in moving water systems that drain the headwaters and feed the streams and lakes downstream. There does not appear to be any scientifically robust, bottom up, analyses that tries to reconstruct the "range of natural variability" of water (spatial and temporal) dynamics prior to the arrival of major land uses, and what types of contemporary water flow patterns can maintain an acceptable level of performance in aquatic systems (fish habitat, fish populations, aquatic invertebrates, fluvial processes, surface/subsurface water dynamics,..). As shown in the image of an ORW headwater stream below (Figure 42), leaving acceptable volumes of water is essential to maintaining ecosystem processes.

Conducting water budgets for the land uses of the ORW is important, and should incorporate factors (such as climate change) that might alter the availability of water today and into the future. Previous research by Schindler and Donahue[53] and Sauchyn[51, 52] reminds ORW residents that water supply can change drastically and that Albertans are likely to experience acute water shortages in the future.

Figure 42. Example of a mid-sized stream flowing off the headwaters of the ORW. The quantity and quality of the water in these streams reflect the matrix of geology, land uses and natural plant communities from which they flow over and through. Photo Credit: Bob Costa.

Previous Studies in Alberta examining effects of coal mining on water

Preface

Whereas heavy metals occur naturally in most surface waters at very low concentrations, even a small increase in concentration can lead to acute and chronic toxicity issues for a broad range of invertebrate and vertebrate organisms inhabiting our aquatic ecosystems. Dr. Bill Donahue has a long career examining the dynamics between land use and water quality, including co-leading several studies with Dr. David Schindler. For the period 2015 to 2019, Dr. Donahue worked for the Government of Alberta as Alberta's Chief Monitoring Officer, the Executive Director of both Monitoring and Science in Alberta Environment and Parks, and as a Visiting Scientist in the University of Alberta's Faculty of Science. Since February, he has begun to analyse Alberta Environment's water quality data from monitoring performed between the late 1990s and 2016 both upstream and downstream of the Luscar, Gregg River, and Cheviot coal mines south of Hinton. Dr. Donahue's analyses are summarized below.

Results

The results are revealing and indicate that concentrations of many water toxicity indicators, including a suite of contaminants routinely associated with coal mining, are much higher downstream of the mines than upstream. In most cases, levels are 2X to 80X higher downstream of the mines, however some, i.e., Co and Ni, increase by more than 100X higher downstream of the coal mines. In general, rivers or streams immediately downstream of coal mines have much higher concentrations of heavy metals (e.g., selenium, lead, manganese, copper, arsenic, cadmium) and nitrogen, and much higher sodium concentrations that contribute to reduced water quality for irrigation. Very large increases in concentrations of a wide variety of chemical water quality indicators downstream of coal mines occurred soon after mining commenced, have persisted over time, and have remained high long after the mines ceased operations and required reclamation actions were well advanced or even completed. Significant changes in downstream invertebrate communities and health of fisheries have also been documented for these three mines. Other than the fact that Alberta Environment and the Alberta Energy Regulator have failed to reveal these facts, none of this is surprising because these problems almost always occur downstream of coal mining, and are exactly the sorts of problems occurring in the Elk River ecosystem downstream of coal mining in southeast BC. The same nature and scale of problems with water quality observed downstream of coal mines in west-central Alberta are all but certain to occur if and where new coal mining operations are commenced elsewhere in Alberta, and especially if they are high-selenium metallurgical coal mines located in headwater regions on the east slopes of the southern Rocky Mountains that otherwise have very high water quality because of their relatively undisturbed catchments.

Water Chemistry Upstream and Downstream of Coal Mines in the MacLeod River System of west-central Alberta. Data prepared by Dr. Bill Donahue, former Chief Monitoring Officer, Executive Director of Monitoring, Executive Director of Science, and Visiting Scientist (University of Alberta), Environmental Monitoring and Science Division, Alberta Environment & Parks.

Starting in the late 1990s and continuing until 2016, Alberta Environment and Parks conducted seasonal water quality sampling immediately upstream and downstream of three large coal mines approximately 50 km south of Hinton, in the headwaters of the McLeod River watershed in west-central Alberta (Figure 43). Respectively, mining began at Luscar and Gregg River in 1969 and 1982, and reclamation began in 1971 and 1982. Active mining ceased at the Gregg River mine in 2000, and at the Luscar mine in 2004. However, the Luscar mine processing plant and site remained in operation for processing coal from the Cheviot mine, which began mining operations in 2005 and continued until 2016. By 2017, 60% of the Luscar mine's 53 km^2 area was reclaimed, and 99% of Gregg River mine's 37 km^2 area was reclaimed, although neither has been certified as reclaimed by the Alberta Energy Regulator (Beale and Boyce 2020).

Water samples were analysed via ICP-MS in a certified lab for a broad range of water indicators, including heavy metals [including those normally associated with coal mining, such as selenium (Se), arsenic (As), lead (Pb), cadmium (Ca), nickel (Ni), mercury (Hg), chromium (Cr), cobalt (Co), magnesium (Mn), Iron (Fe), aluminum (Al), and zinc (Zn)], nutrients [e.g., various species of nitrogen (TDN, NO_3+NO_2), phosphorus (TDP)], and other indicators important to aquatic function, ecosystem health, land use performance, and human health [e.g., dissolved oxygen (DO), acidity (pH), sodium (Na) and sodium adsorption ratio (SAR)]. Initial sampling in 1998 and 1999 demonstrated that selenium concentrations downstream of Luscar and Gregg River mines were an order of magnitude higher than concentration thresholds adopted by Canada and the USA to protect aquatic life, whereas concentrations at relatively undisturbed reference sites upstream of the mines were typically lower than those thresholds (Casey and Siwik 2000, Casey 2005). While early results were analyzed and published by Alberta Environment on the basis of sampling between 1998 and 2003, subsequent analyses and interpretation of data from continued monitoring have not been performed. As such, most Albertans are unaware of the existence of these data that have critical relevance in informing the current public conversation on the almost certain significant harm to downstream aquatic ecosystems that will result from increased coal mining in Alberta.

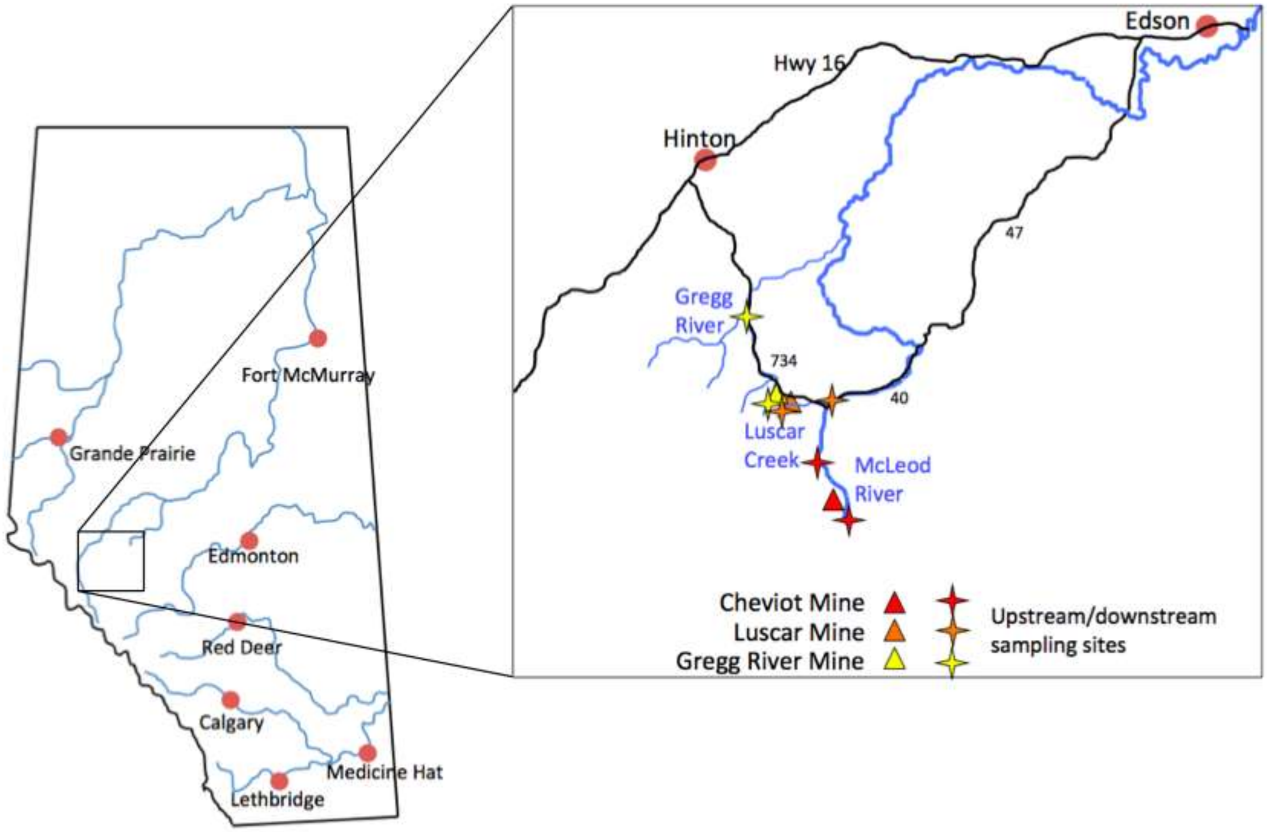


Figure 43. Locations of three coal mines (Cheviot Mine, Luscar Mine, and Gregg River Mine) in the upper McLeod River watershed, and Alberta Environment and Parks' associated upstream and downstream water quality monitoring sites that were chosen to identify effects of the coal mine operations on downstream water quality.

Coal mining around the world is commonly associated with cation, heavy metal, and nutrient pollution delivered via dust and either intentional or unintentional releases of contaminated process water, runoff or groundwater from disturbed mine lands to downstream creeks, rivers, and lakes, and resulting harm to invertebrate, fish and wildlife health and populations (Lemly 1996, 1997, Lindberg *et al.* 2011, Belmer *et al.* 2014). To assess the downstream impacts of the Cheviot, Luscar, and Gregg River coal mines on downstream water quality, data from pairs of samples taken on the same day upstream and downstream of the mines were selected from Alberta Environment's 1998-2016 monitoring dataset. In this way, comparison of downstream to upstream concentrations provides an indication of the degree to which concentrations downstream of coal mines have increased, relative to concentrations upstream at undisturbed sites and without the problems introduced from sampling on different days with potentially different stream conditions. The monthly water quality monitoring upstream and downstream of these three mines by Alberta Environment between the late 1990s and 2016 reveals significant increases in the average concentration of a wide variety of basic water quality parameters, e.g., 3-12x higher turbidity; 1.7-4.3˚C temperature increases; 5-38x higher nitrogen (mostly nitrate, with small amounts of nitrite); 3-31x higher chlorine, substantially higher heavy metals (7-8x higher arsenic; 6-14x higher selenium; 5-26x higher lead; 14-50x higher antimony; 13-50x higher manganese) and cations (e.g., 8-80x higher sodium)(Figure 44, Table 2).

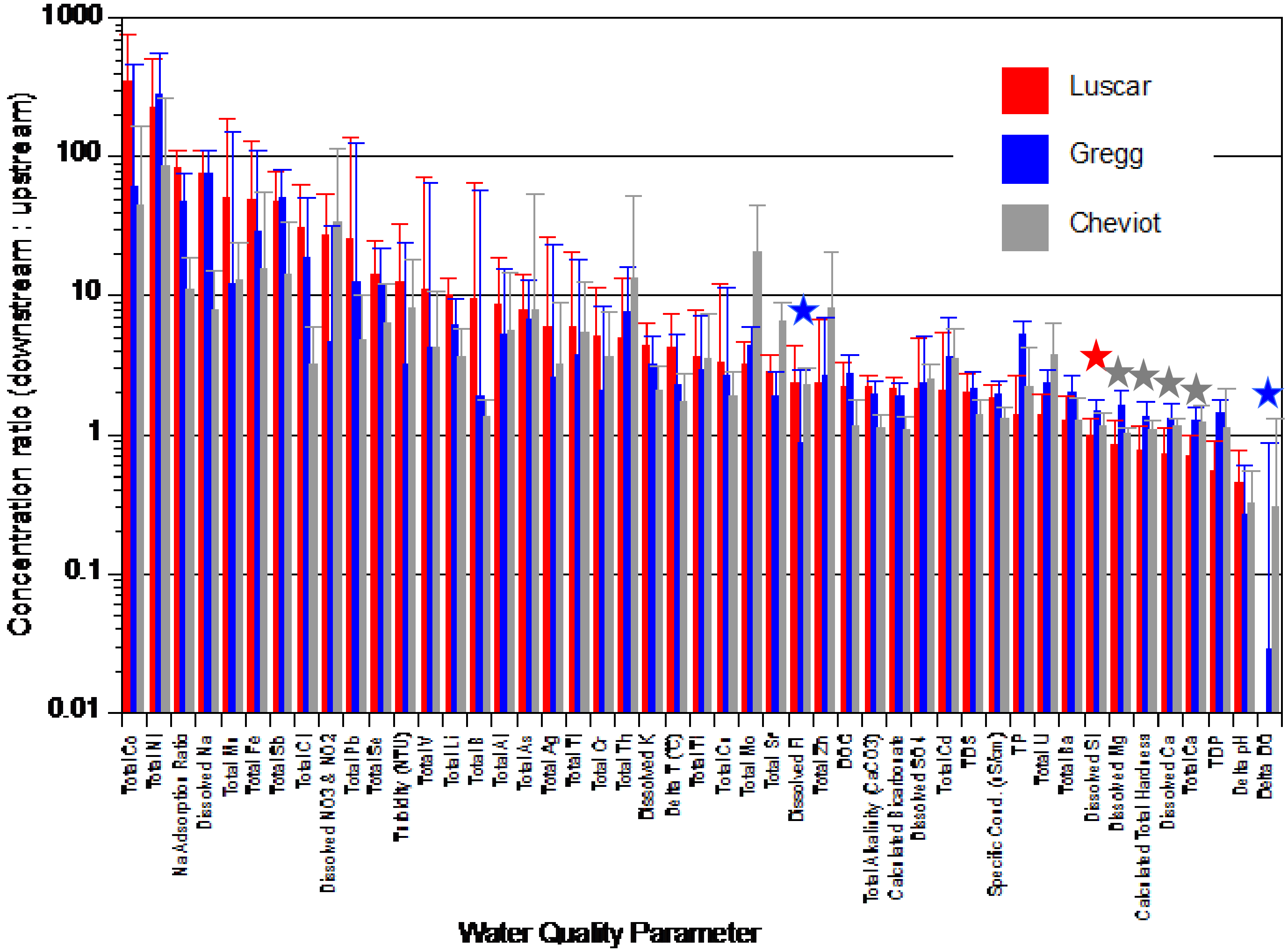


Figure 44. Ratio by which concentrations of water quality parameters increased, relative to upstream concentrations, in rivers or creeks downstream of three coal mines in west-central Alberta's McLeod River watershed (1998-2016 for Luscar and Gregg River mines; 2005-2016 for Cheviot Mine). All ratios are significant at the (P<0.05) level, unless where indicated by a star, coded by colour to match the three mines (one-sample Z-test for mean; two-tailed; compared to hypothesized population mean of 1.000 and a population variance of 0.250). Values for temperature, pH and dissolved oxygen (DO) from upstream to downstream reflect absolute changes, rather than ratios.

Table 2. Average ratio by which concentrations of metals, nutrients and other water quality parameters increased downstream of coal mines, relative to upstream at unimpacted sites (as shown in Figure 45). All ratios are significant at the (P<0.05) level, unless where highlighted in grey (one-sample Z-test for mean; two-tailed; compared to hypothesized population mean of 1.000 and a population variance of 0.250). Values for temperature, pH and dissolved oxygen (DO) from upstream to downstream reflect absolute changes, rather than ratios.

Element or Chemicals	Luscar Creek	Gregg River	Cheviot Mine (McLeod River)
Co	353.2	61.8	44.7
Total Ni	228.0	280.0	140.8
Na	76.7	76.6	8.2
Mn	51.4	12.1	13.0
Sb	47.5	49.2	14.3
Cl	31.4	18.9	3.2
Total Fe	49.3	29.0	23.7
NO3 & NO2	27.2	4.7	37.9
Pb	26.0	12.6	4.9
Se	14.3	11.8	6.4
Turbidity	12.5	3.2	8.2
V	11.3	4.3	4.3
Li	10.3	6.1	3.6
B	9.7	1.9	1.4
Al	8.7	5.2	5.7
As	8.0	6.7	8.0
Ag	6.0	2.6	4.6
Tl	6.0	3.7	5.5
Cr	5.2	2.1	3.7
Th	5.0	7.8	13.4
Dissolved K	4.4	3.2	2.1
DT	4.3	2.3	1.73
Ti	3.7	2.9	3.5
Cu	3.3	2.6	1.87
Mo	3.2	4.4	20.8
Sr	2.8	1.90	6.6
Fl	2.4	0.88	2.3
Zn	2.3	2.7	8.1
Alkalinity	2.2	2.0	1.13
Bicarbonate	2.1	1.90	1.10
SO4	2.1	2.4	2.3
Cd	2.1	3.7	3.5
TDS	2.0	2.1	1.40
Conductivity	1.82	1.94	1.32
TP	1.39	5.3	2.2
U	1.39	2.3	3.7
Ba	1.28	2.0	1.25
Dissolved Si	0.99	1.48	1.14
Dissolved Mg	0.84	1.61	1.03
Hardness	0.76	1.36	1.10
Dissolved Ca	0.73	1.29	1.17
Total Ca	0.70	1.25	1.21
TDP	0.55	1.43	1.10
DpH	0.45	0.27	0.32
DDO	-0.83	0.03	0.31

Downstream Declines in Water Quality

Many of these compounds can have significant negative direct and indirect environmental effects in aquatic ecosystems and foodwebs, but most concern in response to coal mining in western Canada relates to selenium contamination. The bioavailability of selenium varies according to its chemical form, and generally increases with soil oxidation and pH (Lemly 1996, 1997), which is why selenium concentrations in water and biota downstream of coal mines increase. In the case of the three mines listed above, selenium concentrations downstream of the mines averaged approximately 6-14 times higher than upstream of the mines (Figure 45; Table 2). Downstream of Luscar and Gregg River mines there was no change in average downstream concentrations of Se throughout the monitoring period, despite the fact that both mines had closed between 12 and 16 years before monitoring ceased, and average Se concentrations increased quickly and significantly downstream of Cheviot mine during the first decade of operations (i.e., until monitoring ceased in 2016).

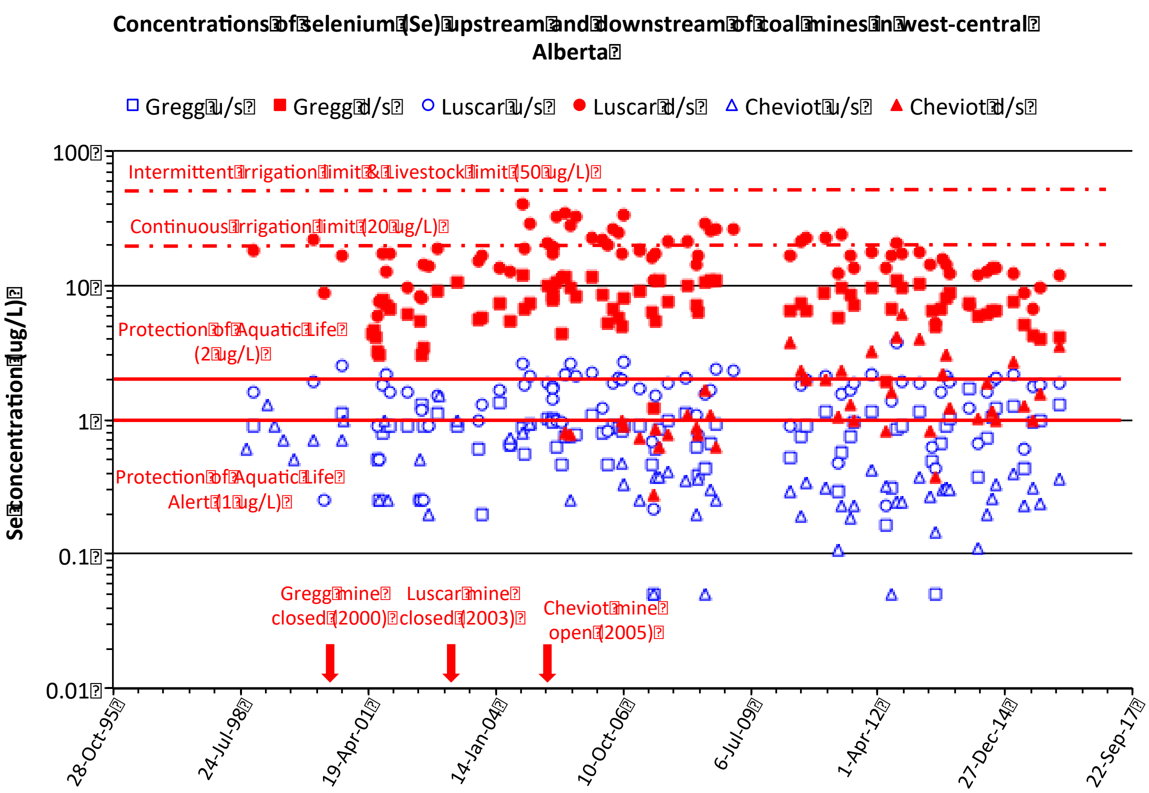


Figure 45. Comparison of selenium (Se) concentrations upstream and downstream of coal mines in west-central Alberta. Source: Alberta Environment and Parks.

Downstream of the Luscar and Gregg River mines, 97-100% of paired samples taken exceeded Alberta's standards for Protection of Aquatic Life (PAL; 2 μg/L) (versus 25% and 0% of samples upstream of the respective mines), and 26% of samples downstream of Cheviot mine exceeded those standards (versus 0% upstream) (Table 3). Maximum concentrations of selenium were 40.6 μg/L in Luscar Creek downstream of Luscar mine, 11.9 μg/L in Gregg River downstream of Gregg River mine, and 6.2 μg/L in the McLeod River downstream of Cheviot mine, far higher than the 2 μg/L above which harm can be expected to aquatic organisms. While concentrations of selenium may be naturally high in Luscar Creek and to a lesser extent in Gregg River, based on elevated concentrations and frequency of exceedances of the provincial water quality guidelines (alert and PAL levels) in samples from undisturbed upstream reference sites, there is no disputing that coal mining has increased selenium concentrations in these systems.

Table 3. Frequency of exceedances of Protection of Aquatic Life water quality limits in Alberta Environment & Park's monitoring program upstream and downstream of coal mines in west-central Alberta, between ~2000 and 2016 (2005 and 2016, for Cheviot Mine).

(light)	Less than 5% of samples exceed limits
(yellow)	5% to 40% of samples exceed limits
(red)	More than 40% of samples exceed limits

		Gregg		Luscar		Cheviot	
		REF	Downstream	REF	Downstream	REF	Downstream
	% Alert (>1 ug/L)**	24%	100%	76%	100%	0%	58%
Se	% PAL (>2 ug/L)**	0%	97%	25%	100%	0%	26%
Chlorine	% Chronic	31%	99%	32%	100%	0%	45%
	% Chronic	22%	51%	18%	68%	33%	79%
Al (ug/L)	% Acute	12%	35%	9%	48%	24%	51%
	% Chronic	4%	4%	0%	0%	0%	3%
Cd	% Acute	0%	0%	0%	0%	0%	0%
	% Chronic	4%	4%	0%	1%	0%	3%
Cr	% Acute	0%	0%	0%	0%	0%	0%
	% Chronic	0%	7%	0%	0%	0%	3%
Cu	% Acute	0%	0%	0%	0%	0%	0%
Pb	% Chronic	4%	4%	0%	0%	0%	3%
Zn	% Chronic	0%	4%	0%	1%	0%	2%

Clearly, selenium is a severe and long-lasting problem that has resulted from coal mining in the upper McLeod Watershed. It also is notable that Alberta has long adopted and advertised a water quality standard of 1 μg/L for Se as the purported trigger for a management response that includes much more robust environmental monitoring and research, to identify reasons for increases and potential mitigation options to ensure concentrations do not continue to increase to exceed the 2 μg/L levels that are needed to protect aquatic life. However, despite having identified that Se concentrations exceeded PAL limits by almost 10-fold within the first two years of monitoring, those preventative and mitigative management responses appear not to have been triggered. Instead, very high Se concentrations continued to be documented downstream of existing coal mines, while the Cheviot mine was permitted to open and contaminate the McLeod River downstream of it. That concentrations of contaminants downstream of the west-central Alberta coal mines remained elevated almost two decades after their closure is consistent with similar documentation of continuing contamination of streams by mountaintop coal mines in the Appalachian region of the United States almost two decades after their regulatory reclamation was completed (Lindberg *et al.* 2011).

While concentrations of most metals and other elements or compounds increased significantly downstream of the three coal mines (Figure 44; Table 2), only nitrogen, chlorine and aluminum are described in more detail, as examples of the negative effects of coal mining on downstream water quality. Those that are not presented or described all demonstrate similar patterns of downstream increases, as indicated by Figure 44. It also should be understood that Alberta's water quality standards have only been developed for some of these chemicals, and where the toxicological effects and risks on aquatic invertebrates, fish, or wildlife has been determined for a chemical, it is normally assessed in isolation. Consequently, water quality standards or limits for individual chemicals will not account for any interactive, additive, or multiplicative toxicological effects of simultaneous elevation of a cocktail of contaminants, such as is experienced downstream of coal mines. That is to say, a lot is not understood about the risks to aquatic ecosystem health that result from the chemical soups released by coal mining into downstream streams and rivers.

Concentrations of nitrogen, primarily in the form of nitrate (NO_3) but with very low concentrations of nitrite (NO_3), increased by an average of ~5x to 38x downstream of the three mines, resulting in periodic exceedances of the 3mg/L toxicological limit required for the protection of aquatic life (Figure 46). While concentrations remained high downstream of Gregg River and Luscar mines, exceedances of the PAL limit for nitrate ceased to be evident in

the paired samples after 2009, whereas concentrations downstream of Cheviot mine began to increase immediately after its 2005 opening, and began to exceed PAL limits in 2012 and continued thereafter. The limit for nitrate indicated for the protection of aquatic life is purely toxicological and does not account for the significant ecological impacts that increased nitrogen in aquatic ecosystems can cause, including eutrophication and increase in nuisance algae (Carpenter *et al.* 1998, Sosiak 2002, Chambers *et al.* 2006, Saffran and Anderson 2009). The large quantities of nitrogen-based explosives that are used in coal mines in Alberta have been suggested as source of elevated downstream nitrate concentrations, although this remains to be determined. However, nitrogen-based explosives used in coal mines in B.C.'s Elk Valley increased nitrate concentrations from an average of 0.20 mg/kg in pre-blast rock to an average of 27.6 mg/kg in fresh-blast rock, and that leaching from on-site waste-rock dumps is the source of downstream nitrate (Mahmood 2016).

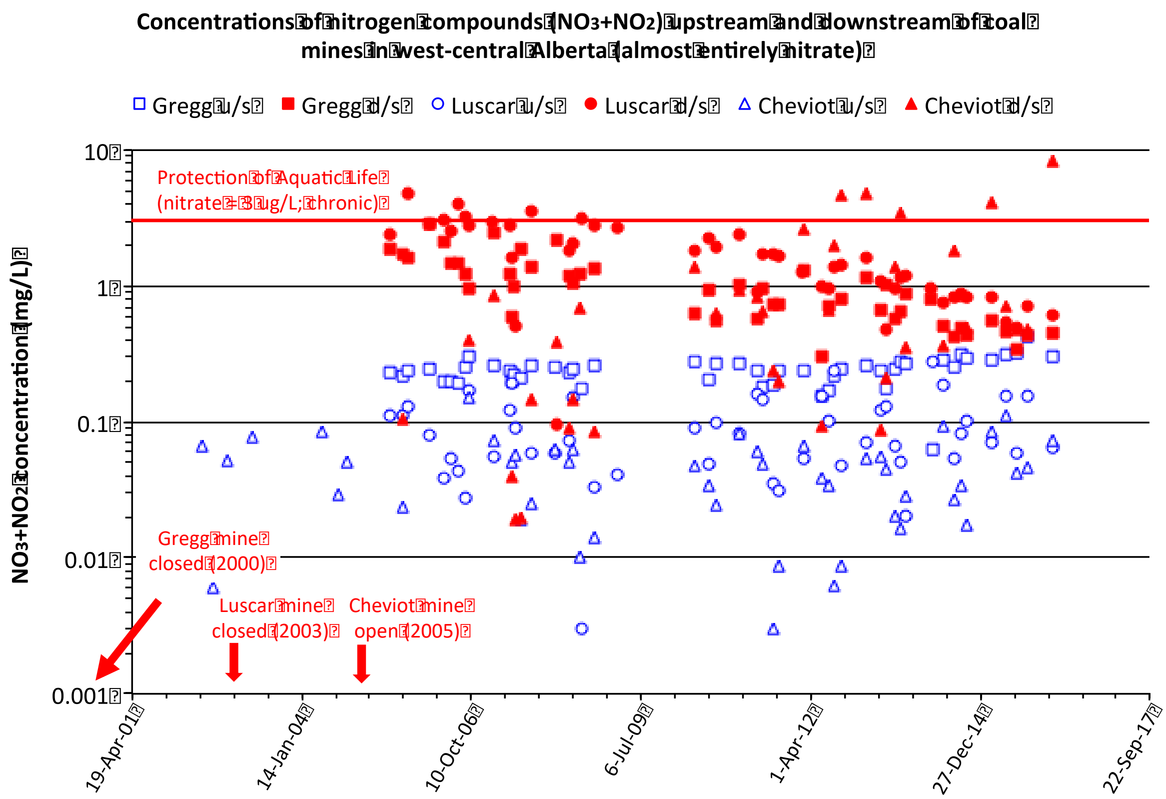


Figure 46. Comparison of Nitrogen (N) concentrations upstream and downstream of coal mines in west-central Alberta. Source: Alberta Environment and Parks.

Relative to upstream concentrations, average increases in concentrations of chlorine downstream of the coal mines were elevated by 3.2-31.4x (Table 2). Effectively all paired samples (99%) downstream of the Gregg River mine exceeded the water quality guideline for protection of aquatic life for chlorine (0.5 μg/L), whereas all paired samples downstream of the Luscar mine exceeded that limit (Table 3; Figure 47). As with selenium, exceedances of PAL limits for chlorine upstream of the Gregg River (31%) and Luscar (32%) mines suggests that the Gregg River and Luscar Creek may be naturally high in chlorine, likely because of the prevalence of coal in these watersheds. Fewer of the paired samples taken downstream of Cheviot mine exceeded the PAL limit for chlorine (45%) than for the other two mines. However, there were no exceedances of the PAL in samples from the McLeod River reference site upstream of the mine. Further, unlike for the other two mines, concentrations downstream of Cheviot mine demonstrated an increasing trend after the mine opened in 2005, with more frequent exceedances of the PAL limit after 2010. Both of these factors highlight the mine itself as the reason for increasing chlorine concentrations and risk to aquatic life downstream of the mine.

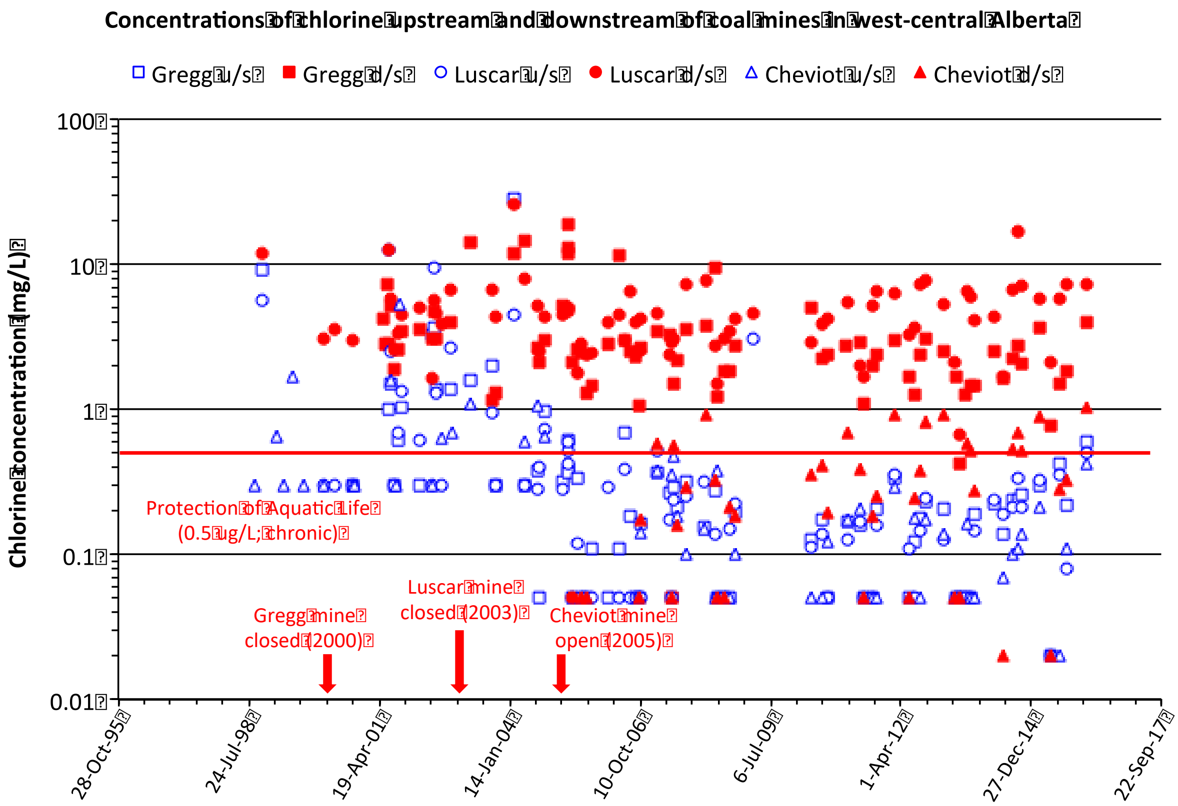


Figure 47. Comparison of chlorine (Cl) concentrations upstream and downstream of coal mines in west-central Alberta. Source: Alberta Environment and Parks.

Aluminum concentrations downstream of the coal mines were on average 5.2-8.7x higher than upstream concentrations (Table 2) and exceeded both chronic and acute limits for protection of aquatic life upstream and downstream of all three mines (Table 3; Figure 48). However, unlike for selenium and chlorine, the frequency of exceedances of the PAL limits was highest downstream of Cheviot mine. Background exceedances suggest natural sources of aluminum, and in addition to the direct impacts of mining increasing concentrations and the frequency of exceedances, it is likely that natural erosion sources contributes to naturally high aluminum concentrations in these systems.

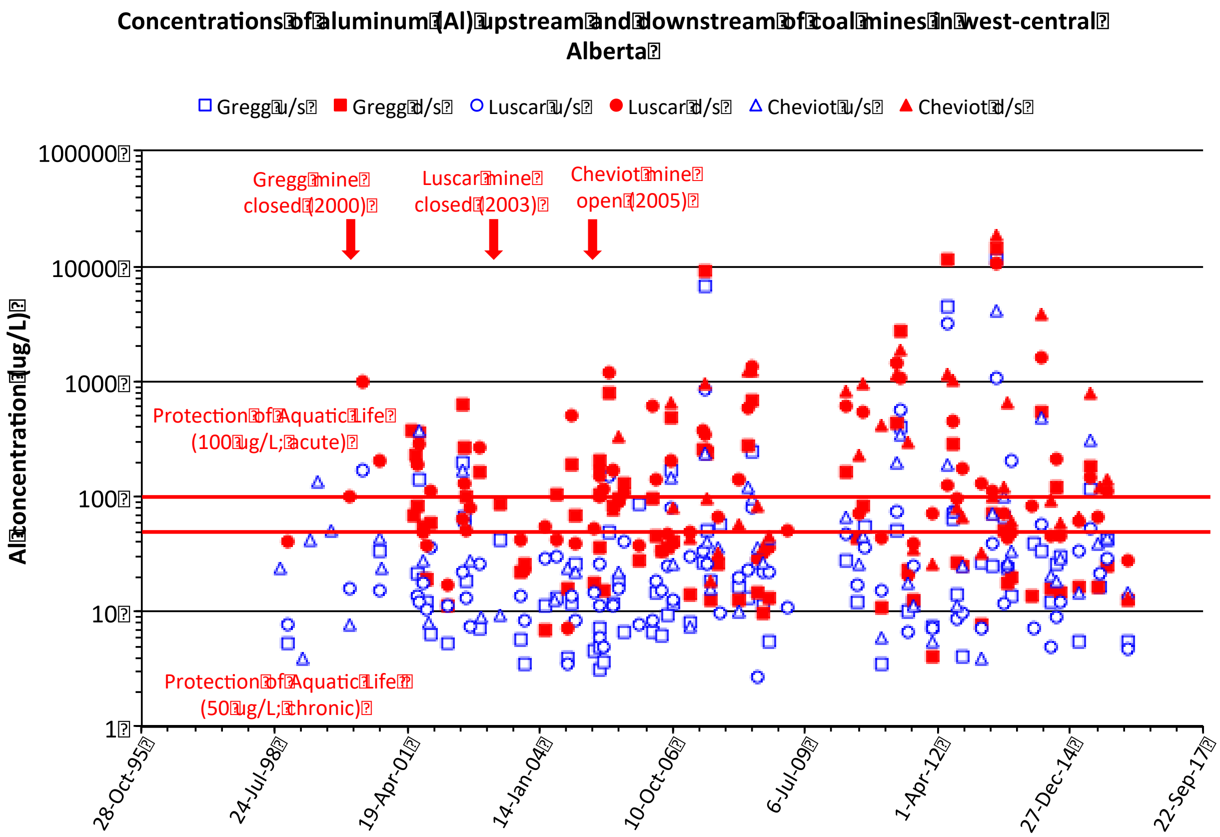


Figure 48. Comparison of aluminum (Al) concentrations upstream and downstream of coal mines in west-central Alberta. Source: Alberta Environment and Parks.

Aquatic Invertebrates

Aquatic invertebrates, and in particular some classes of insects (mayflies, stoneflies, and caddisflies, i.e., Ephemeroptera, Plecoptera, and Tricoptera; "EPT") are important indicators of aquatic ecosystem health and human impact, including in assessment of water quality, sedimentation, and metal toxicity, and are particularly sensitive to stream impairment (Kuchapski and Rasmussen 2015b). They also are critically important prey species for coldwater fish, like the various species of trout (including Westslope cutthroat trout) that inhabit the headwaters of Alberta's major watersheds.

In addition to large increases in water concentrations of selenium downstream of coal mines in the upper McLeod River watershed, higher selenium concentrations were also identified in the late 1990s and early 2000s in downstream biofilm and in some EPT families, along with increases in concentrations of arsenic and zinc in one or more of these groups of aquatic insects (Casey and Siwik 2000, Wayland and Crosley 2005). A 2011 survey of benthic invertebrate communities in reference streams, and streams impacted by these three coal mines revealed significant changes in benthic invertebrate communities downstream of the coal mines. This included declines in mayfly density and community richness, declines in EPT community richness, and declines in mayflies densities relative to the full aquatic invertebrate community structure, that corresponded with increases in the degree of physical disturbance (e.g., calcite accumulation and sedimentation) caused by the coal mines, as well as the downstream chemical changes to these systems that included not only potential selenium toxicity but also increases in alkalinity, conductivity, and concentrations of ions like chloride and magnesium (Kuchapski and Rasmussen 2015b). In the same study, similar negative effects of coal mining on aquatic insect communities were documented downstream of coal mines in the Elk River basin, in southeastern B.C. So it is not a stretch to conclude that similar changes to invertebrate communities will follow the downstream declines in water quality and increases in physical disturbance that expanded coal mining in southwestern Alberta will cause.

Fish and Biodiversity

A recent scientific review concluded that, on average, biodiversity is 32% lower and abundance is 53% lower in US streams affected by coal mining, relative to streams in unmined watersheds, and that those declines were consistent among invertebrate communities, fisheries, and salamanders (Giam, Olden and Simberlofff 2018). Changes in benthic invertebrate community structure and density are particularly important, not only as indicators of aquatic ecosystem health and changes in water and sediment quality, but also as indicators of potential harm from coal mining to fish populations. Selenium concentrations in rainbow trout eggs collected in the upper McLeod River basin in 1999 were higher than in female fish muscle, and both were positively correlated with water concentrations, lowest at undisturbed reference sites and highest downstream of mines (Casey and Siwik 2000). At that time, conceptual modeling of foodweb effects of bioconcentration and bioaccumulation predicted adverse effects in various fish species in these systems, and laboratory toxicity studies on rainbow trout fry confirmed this conclusion (Casey 2005).

In 2011, significant increases in selenium concentrations were documented at each level of the aquatic foodchain in the upper McLeod River watershed, including in water, biofilm, invertebrates, and juvenile rainbow and brook trout (Kuchapski and Rasmussen 2015a). Selenium accumulation from invertebrates to juvenile trout muscle tissue did not vary among fish species, but muscle tissue concentrations were strongly correlated to dietary selenium concentrations at the site at which juvenile fish were captured (i.e., concentrations in benthic aquatic invertebrates). A significant negative relationship also was observed between muscle selenium concentration and total fish biomass in stream reaches for rainbow trout. Total rainbow trout biomass was 0.07 g/m^2 in the stream reach with the highest mean muscle selenium concentration (15.07 mg/kg dry mass; mine-impacted stream), compared to total rainbow trout biomass of 2.25 g/m2 in the stream reach with the lowest mean muscle selenium concentrations (3.14 mg/kg dry mass; reference stream).

So an almost 5-fold increase in rainbow trout muscle selenium concentrations corresponded with a 93% decline in total fish biomass (i.e., fewer fish and of smaller size). However, there was no relationship between total biomass and muscle tissue selenium concentrations for brook trout (Kuchapski and Rasmussen 2015a). Average selenium concentrations in muscle in rainbow trout in mine-affected reaches in McLeod River streams also exceeded levels at which larval deformities are anticipated as determined by Holm et al. (2005) and Alberta's selenium fish tissue guideline for protection of aquatic life (4 μg/g dry mass). Out of all of the measured fish habitat and water quality characteristics that were described in this study for each stream reach studied, selenium exposure was the only one that was a strong predictor of total fish biomass in each reach, and the study authors were unable to construct any habitat model that predicted total fish biomass. All of this strongly suggests that high selenium exposure caused by the coal mines in the upper McLeod River watershed is the primary contributing factor to observed declines in rainbow trout populations in mine-affected stream reaches.

All of the declines in water quality, diversity and abundance of invertebrates, and rainbow trout populations downstream of coal mines in the upper McLeod River watershed are consistent with impacts from coal mining identified elsewhere, including in the Elk River basin in BC and throughout the continental USA. Therefore, there is no reason to believe that all of the declines in aquatic ecosystem quality and health that have already been observed downstream of coal mining in the upper McLeod river watershed should not be expected to also occur downstream of other coal mines in Alberta.

Downstream Declines in Water Quality for Irrigation

While most public attention is on the direct toxicological effects to aquatic organisms of increases in concentrations of a variety of chemicals caused by coal mining, declines in water quality as related to suitability of irrigation is nonetheless potentially of real significance in southern Alberta, particularly in the Oldman River watershed. In particular, downstream changes in the specific conductance or the chemical balance between sodium, calcium and magnesium in water because of coal mining or coalbed methane development results in significant shifts in the downstream quality of irrigation water (Cannon *et al.* 2007). Coal mining in the McLeod River headwaters resulted in 77-fold average increases in sodium concentrations downstream of both the Luscar and Gregg River mines, and more than an 8-fold increase downstream of Cheviot mine, with slight declines or moderate increases in downstream calcium and magnesium concentrations (Figure 44; Figure 49; Table 2).

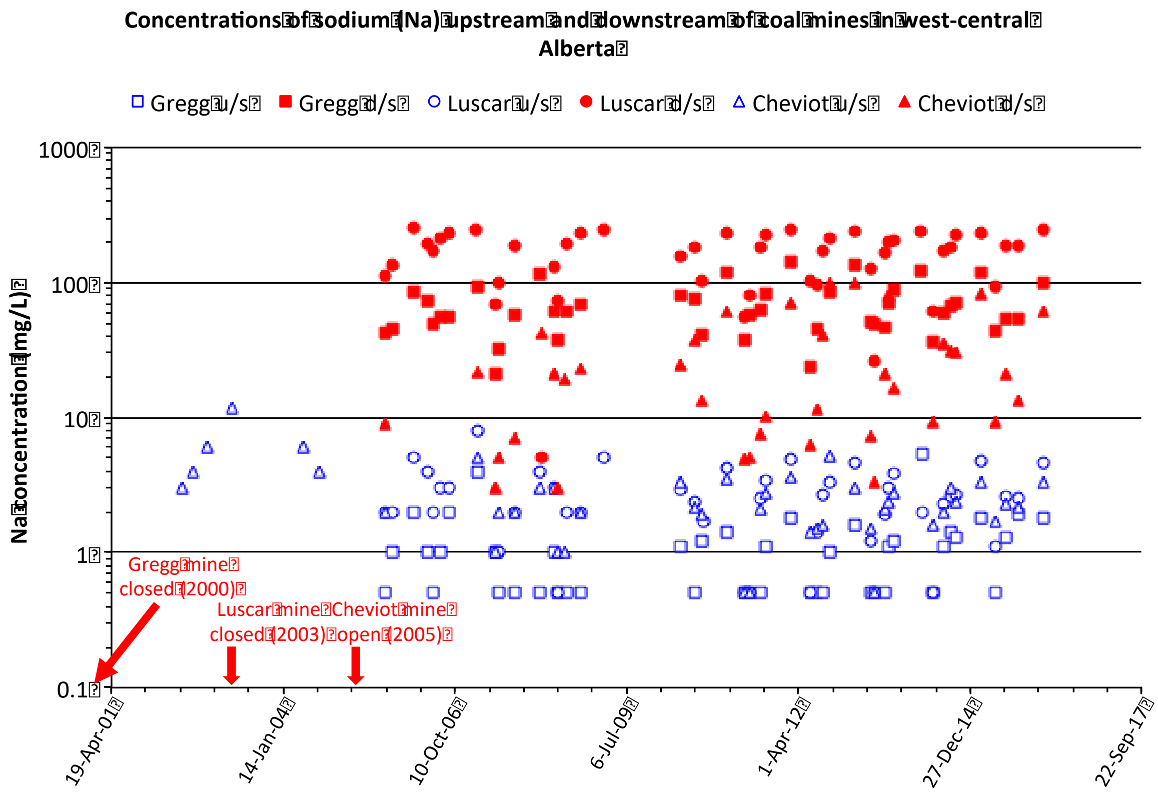


Figure 49. Comparison of sodium (Na) concentrations upstream and downstream of coal mines in west-central Alberta. Source: Alberta Environment and Parks.

Concentrations of these three elements (measured in milliequivalents/L) are used to calculate the sodium adsorption ratio (SAR), which is one of the indicators of irrigation water quality commonly used (Cannon *et al.* 2007, Bulltail and Walter 2020):

$$SAR = \frac{Na}{\sqrt{\frac{(Ca + Mg)}{2}}}$$

In short, when SAR increases, it can influence soil structure and thereby reduce permeability and water infiltration rates, which obviously can reduce the effectiveness of irrigation and crop production. Therefore, if sodium concentrations increase disproportionately more than calcium and magnesium, then SAR increases and irrigation water quality declines. Alberta defines water with an SAR less than 5 as safe for irrigation use and an SAR greater than 10 as hazardous for irrigation use; when SAR is between 5 and 10, it is characterized as "possibly safe" for irrigation purposes, however one could equally characterize it as possibly hazardous for use in irrigation. In the large majority of paired samples, SAR increased substantially downstream of the three coal mines (Figure 50). However, only downstream of Luscar mine did water quality routinely decline enough to be characterized as "possibly safe" (or possibly hazardous). On average, relative to upstream samples, SAR increased by 5.4 units downstream of Luscar mine, by 2.0 units downstream of Gregg River mine, and by 0.8 units downstream of Cheviot mine.

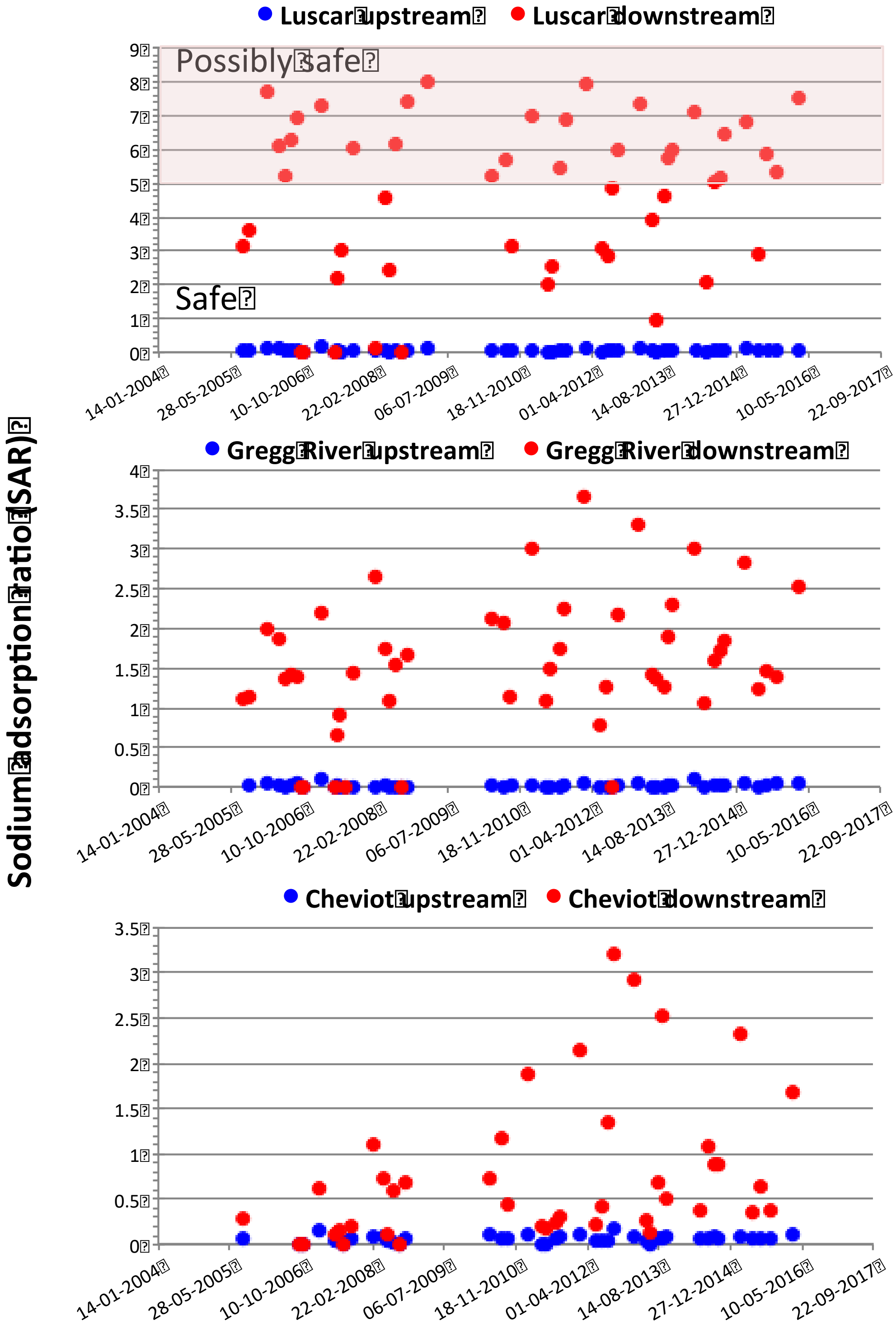


Figure 50. Differences in sodium adsorption ratio (SAR) in paired samples from upstream and downstream of coal mines in west-central Alberta, as an indicator of suitability for use in irrigation [Safe ≤ 5; 5<Possibly Safe<10; 10<Hazardous]. Source: Alberta Environment and Parks.

Similar to SAR, increases in specific conductance are also used to indicate declines in water quality for irrigation purposes. Alberta defines water with a conductivity less than 1000 µS/cm as safe for irrigation use, and greater than or equal 2000 µS/cm as hazardous for irrigation use; as with SAR, when conductivity is between those two values, it is characterized as "possibly safe" (or possibly hazardous) for irrigation purposes. Relative to paired daily samples taken upstream, the average increase in downstream conductivity was 82% (+412 µS/cm) for Luscar mine, 94% (+348 µS/cm) for Gregg River, and 32% (+128 µS/cm) for Cheviot mine (Table 2). Consequently, water quality downstream of Luscar mine routinely shifted from "safe" for irrigation to "possibly safe" (or possibly hazardous), but, unlike for SAR, water quality downstream of Gregg River mine also demonstrated sufficient increases in specific conductance to periodically cross the threshold from "safe" to "possibly safe" (Figure 51). Overall, while SAR increased significantly downstream of all three coal mines, water in Luscar Creek shifted from universally safe for irrigation use upstream of Luscar mine, to possibly hazardous for irrigation use 61% of the times sampled downstream of the mine (Figure 52). Based on specific conductance, which also increased substantially downstream of all three coal mines, water quality for irrigation use shifted from universally safe upstream to possibly hazardous 8% of the times sampled downstream of Gregg River mine, and 54% of the time downstream of Luscar mine. Finally, it should be noted that water quality standards for irrigation use were exceeded because of high selenium concentrations in more than 30% of samples downstream of Luscar mine (Figure 45). Whether because of increases in SAR, specific conductivity, or even selenium, there is no reason to think similar declines in the safety of water for irrigation use will not occur downstream of any new selenium-rich metallurgical coal mines that are opened in the headwaters of the Oldman River watershed.

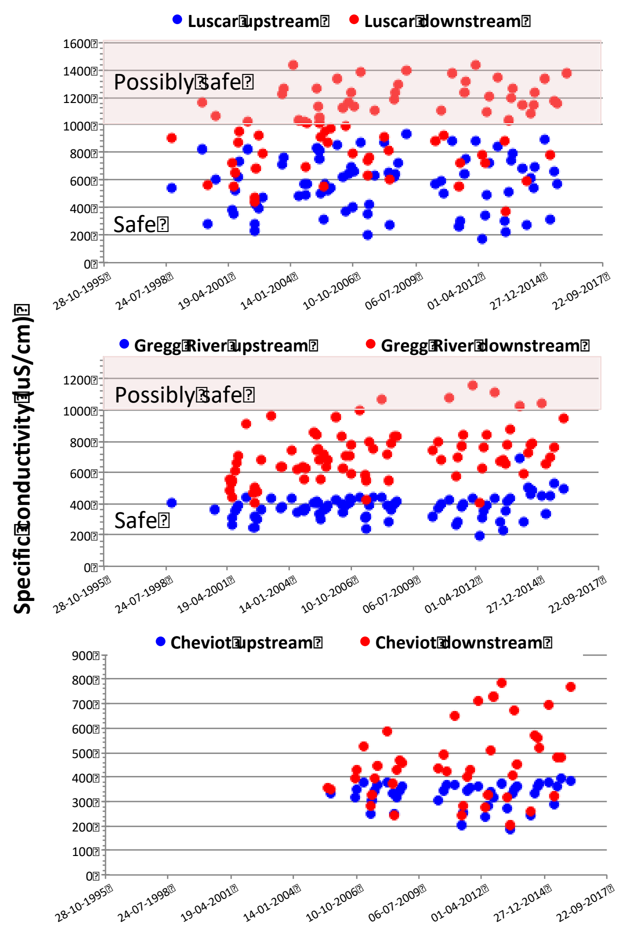


Figure 51. Differences in conductivity in paired samples from upstream and downstream of coal mines in west-central Alberta, as an indicator of suitability for use in irrigation [Safe < 1000; 1000<Possibly Safe<2000]. Source: Alberta Environment and Parks.

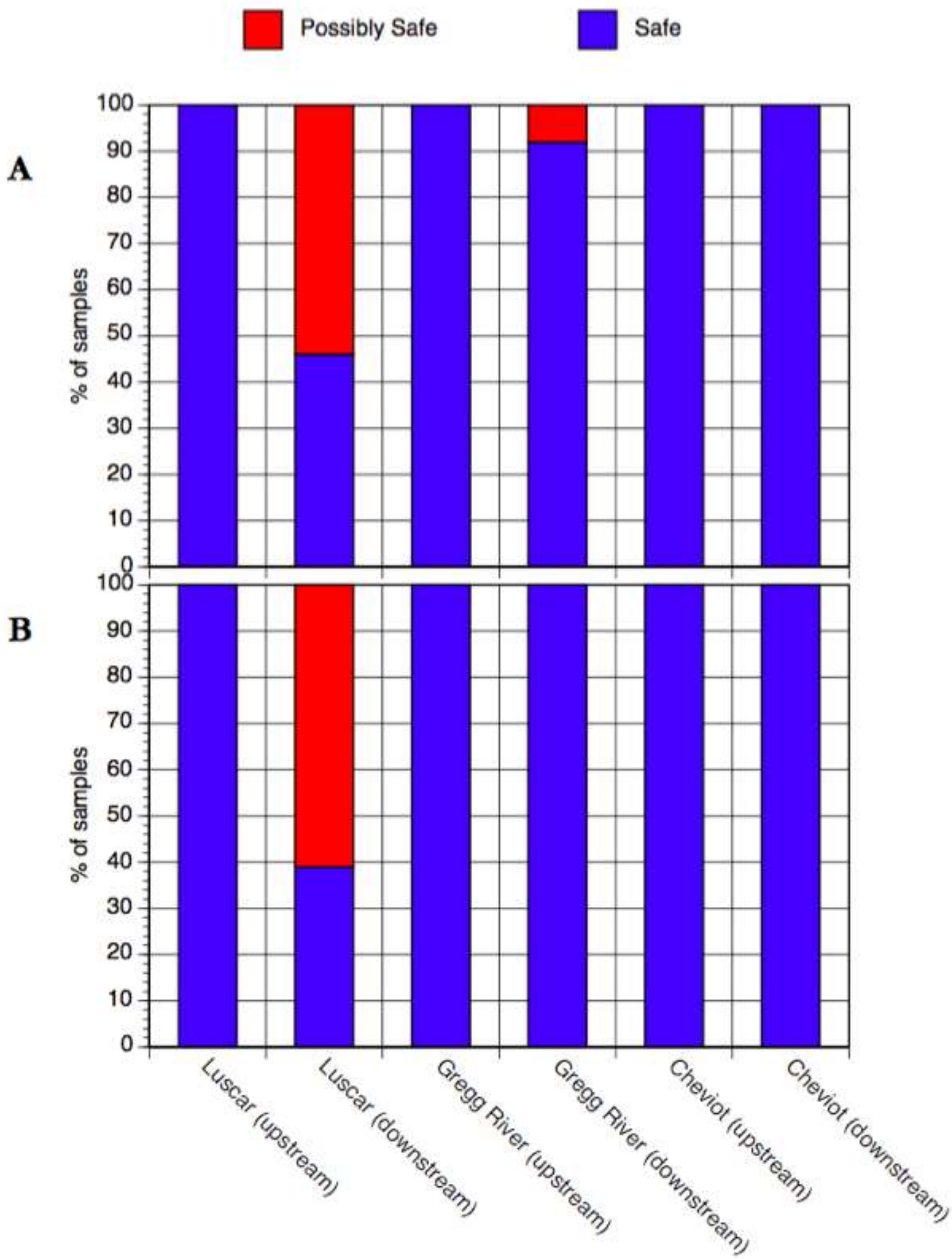


Figure 52. Changes in water quality for irrigation purposes downstream of coal mines in the upper McLeod River watershed: A) percent of samples that are "safe" (<1,000 uS/ cm) and "possibly safe" (1000 uS/cm<x<2000 uS/cm), based on specific conduc3vity; and B) percent of samples that are "safe" (<5) and "possibly safe" (5<x<10), based on sodium adsorption ratio (SAR).

Persistent Post-Reclamation Problems

Given the significant and long-lasting risks posed to ecosystem accumulation, function and toxicity by selenium and other pollutants associated with coal mining, for example in the upper McLeod River watershed in Alberta and in southeastern B.C., industry and government promises of post-reclamation returns to ecosystem function or high-value fish habitat to follow development of new mines in south-west Alberta should be considered highly questionable. In recent weeks, in response to growing public concern in Alberta about the significant environmental harm that would be caused by expanded coal mining, it has been suggested by industry contractors that methods are available to reduce long-term downstream harm from coal mining via such things as novel conversion of coal mine pits to end-pit lakes, such as has been done for Luscar mine's 51-C6 pit that is now referred to as "Sphinx Lake" (Weber 2021).

However, at least five years after that end-pit lake was established and the mine pit deemed reclaimed, in 2008 "all measured [water quality] parameters for which there are federal guidelines (CCME, 2003) were below those guidelines except for selenium" and still as high as 5.9 μg/L (Brinker, Symbaluk and Boorman 2011). While selenium concentrations were described as "trending downward" in that end-pit lake in 2008, at that time selenium concentrations in Luscar creek downstream of the closed Luscar mine remained as high as they had been and were consistently greater than 20 μg/L, and remained far above water quality limits for the protection of aquatic life until the termination of sampling in 2016. Luscar and Sphinx Creeks, downstream of Luscar mine and its reclaimed end-pit lake also were both among the five mine-affected streams studied in the Upper McLeod watershed by Kuchapski and Rasmussen (2015), in which they identified significant changes in invertebrate communities, significant increases in rainbow trout muscle selenium concentrations, and significant reductions in total rainbow trout biomass that corresponded with high selenium exposure.

In terms of end-pit lakes being presented as some sort of healthy or useful post-reclamation site for recreational fisheries, after studying selenium bioaccumulation trajectories in end-pit lakes in reclaimed coal mines in west-central Alberta - including at Luscar and Gregg River mines - it was concluded that "high Se exposure in metallurgical coal pits indicates that under the current mining and reclamation strategy, these lakes are not suitable for management as recreational ‘put and take’ fisheries" (Miller, Rasmussen and Palace 2013). They also highlighted that end-pit lakes in reclaimed metallurgical coal mines in Alberta are particularly high in selenium, and while they may be suitable for stocking and growing fish, "they may pose a significant problem for managers because the Se that bioaccumulates in their tissues may exceed guidelines for human consumption and pose a hazard to wild vertebrate predators."

As described above, the Luscar, Gregg River, and Cheviot coal mines in the headwater region of the McLeod River in west-central Alberta have caused clear long-term harm to downstream aquatic ecosystems, almost immediately after opening in the case of Cheviot mine, during operations of all three mines, and for the entirety of up to almost two decades of sampling that continued after the closure and reclamation of Gregg River and Luscar mines. Declines in physical and chemical characteristics of downstream streams and rivers have led to major changes in invertebrate communities, and to increased selenium exposure that has most likely resulted in huge declines in rainbow trout populations. These sorts of major negative downstream impacts are routinely reported where coal mining occurs, including in the United States, Australia, China, Europe, and British Columbia. The persistence of toxic selenium concentrations and substantially reduced water quality, environmental condition and aquatic ecosystem health downstream of not only active coal mines, but also those that have been long-closed and purportedly reclaimed, should be of great concern in relation to any new coal mines that are considered, planned or approved in the headwater regions of Alberta.

Other Considerations of Coal Mining in Alberta's East Slopes

The Environmental Consequences of Coal Mining

The global literature[102] examining the environmental effects of coal mining is large and documents consequences at a range of temporal and spatial scales (including Crowsnest Pass, the Coal Branch region of west-central Alberta, Elk Valley, BC, and Appalachia region of southeast USA). Summary literature includes consideration of the exploration, mining and the combustion phases of this sector[103]. Environmental liabilities of surface coal mining can be generally classified into categories that include water quantity, water quality, air quality, landscape transformation, biodiversity, climate change, human health, and landscape aesthetics.

Potential water quality issues relevant to coal mines in the ORW include toxic chemicals, heavy metals[104], selenium toxicity[105], calcite deposits[106], altered salinity[107], alkalinity, and overall loss of the utility of water for ecological function and downstream water use.

Water quantity issues generally focus on gross and net water use by coal mining operations, how coal mining activities can alter surface and subsurface water flow, and how coal mining can lead to, or exacerbate, water scarcity to downstream water users.

Air quality concerns associated with coal mines vary regionally and include atmospheric pollution involving coal dust and particulates[108]. Dust generated during extraction can present an occupational hazard for miners and has been linked to pulmonary diseases such as coalworkers' pneumoconiosis (CWP, "black lung disease"), chronic obstructive pulmonary disease (COPD), and silicosis (NIOSH, 2011).

Surface mining for coal in foothill and mountainous regions can lead to large-scale landscape transformation and loss of natural habitat, altered topography (mountain-top removal, filling-in of valleys), and fragmentation of remaining natural habitat.

The magnitude of effects of coal mining on overall biodiversity remains largely unstudied, but numerous studies have documented adverse effects on high profile or keystone species (WSCT, Grizzly bear, bighorn sheep) and aquatic invertebrates[109].

For those hydrocarbons (coal, bitumen, gas, oil) that can be extracted and combusted, coal has undeniably the highest adverse effects on climate change[110]. Coal mining and combustion is broadly recognized to be the greatest global threats of any fuel type[111] to climate instability, and as such, numerous international organizations and governments have called for its abandonment as quickly as possible. It has the highest carbon intensity of the major fuel types (coal, oil, natural gas)[112,113] and has a comparatively large disturbance footprint[114] (Figure 8). Both the Canadian and Alberta government[115,116] have passed legislation that calls for an accelerated phasing-out of surface coal mining by 2030[117]. Alberta's opposition party (NDP) has recently attempted to introduce legislation that would ban all coal mining in Alberta's East Slopes[118,119]; a proposal that was rejected by the UCP government[120].

If the published and recoverable coal reserves for the eight proposed coal mines (Grassy Mtn, Tent Mtn, Elan South, Isolation South, Isola, 4-Stack, Chinook/Vicary, Cabin Ridge) within the ORW are extracted and combusted within the next 50 years, a total of ~1.91 B tonne of $C0_2e$ would be emitted (inclusive of combustion phases). Given that Alberta's 2017 total $C0_2e$ emissions were 272.8 M tonne/yr, the cumulative $C0_2e$ emissions (full life cycle) from prospective coal mining (high growth scenario) represents 7 times the current annual $C0_2e$ emission of Alberta. Phrased differently, the average annua $C0_2e$ emission from prospective coal mining of 38.2 M (full life cycle) tonne would equal 14% of Alberta's 2017 annual emissions.

In the Elk Valley immediately to the west of our study area, ~830 MT of coal have been produced to date[121], with current annual coal production rates of ~25-30 MTA. Using a generalized life cycle methodology (production, cleaning, transport, combustion), Lars Sander-Green of the Wildsight[122] indicate that the total GHG emissions from Elk Valley exceed all other sources in the Province of British Columbia. His approach estimates an average of 2.75 tonne of CO_2e (full life cycle approach) will be emitted for each tonne of coal produced (https://wildsight.ca/2020/06/01/do-we-really-need-steelmaking-coal/).

Systemic health concerns of coal mining[123,124] range from people consuming toxic water (selenium[125]) to inhaling toxic air (coal dust, particulates) to absorbing caustic substances through their skin[126]. Coal-related pathologies include pulmonary disease[127], gastro-intestinal impairment, cancer, neuro-toxic symptoms, to reproductive impairment, …). As summarized by the 2018 meta-study completed by Cortes-Ramirez (2018), "*There is consistent evidence of the association of coal mining with a wide spectrum of diseases, especially cancer and congenital anomalies, in populations resident or in proximity of the mining activities.*"

Selenium and Bighorn Sheep in the Coal Branch region of west central Alberta

Metallurgical coal mining has been a significant land use in the Coal Branch region of west-central Alberta for the past several decades (Figure 54). The cumulative footprint area within the Upper Macleod River watershed is estimated at 7,552 ha (Alces Online), with significant portions of the mine sites now reclaimed. Some of these coal mine sites overlap with traditional bighorn sheep range, whose population size and composition during and following coal mining have been monitored for several decades. Population demographics of bighorn sheep herds on these reclaimed sites are monitored the Government of Alberta and by coal sector consulting biologists (see Beth McCallum[128],[129]). Rams are known to possess comparatively large horns, which presumably reflects their high nutrient diet (abundance of agronomic and leguminous plant on reclaimed sites) and high survivorship (low harvest rates by predators and hunters).

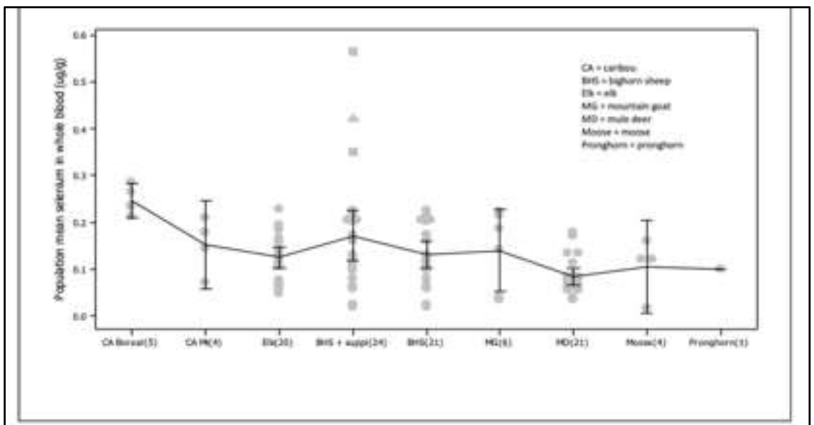
In recent decades, some individuals in the public have expressed concerned that bighorn sheep on these sites exhibited unnatural horn morphology, and suggested these anomalies might be attributed to environmental toxicity associated with the coal mines. Selenium has been suspected as a potential toxin since it is a persistent element proximal to coal mines and has a narrow safe operating level for many vertebrate and invertebrate species.

Recently, Jeff Kneteman[130], a retired provincial wildlife biologist, completed a study (2016) examining blood chemistry of bighorn sheep (and other ungulate species) in the Coal Branch region of west central Alberta and several other locations in North America. His work indicates that bighorn sheep populations residing in and near coal mine sites exhibit higher "whole blood" selenium concentrations than do other non-supplemented populations (Figure 55, Figure 56). Kneteman's research is preliminary in nature, does not examine actual causal pathways, but does indicate a pattern that deserves additional attention. An excerpt from the Government of Alberta's draft Bighorn Management Plan provides additional context on the possible effects of selenium in bighorn sheep.

Trace minerals are essential for sustaining vital functional physiology, particularly relating to growth and immune function in many species. In ungulates selenium plays a role in structural, metabolic, reproductive, and immune functions and can directly and indirectly affect population dynamics (Flueck 1994). Many mammalian species have a narrow tolerance for selenium (Terry et al. 2000, Trumble and Sorensen 2008, Quinn et al. 2011) and levels considered deficient or excessive can have serious consequences to individual animal health (Ohlendorf 1996, Wobeser 2006). However the interval between adequate and safe selenium bioavailability is unknown in ungulates (Poppenga et al. 2012). Severe deficiency or toxicity is rarely diagnosed in wildlife; apparent low levels may be offset by other elements, such as vitamin E (Dunbar et al. 1999). However, marginal deficiency at chronic subclinical levels may be a management concern, especially on poor quality ranges (Flueck et al. 2012). In regard to bighorn sheep, natural and agronomic forages in the eastern slopes region of Alberta (Samson et al. 1989) generally are low in selenium content measured against information pertaining to domestic sheep. But using domestic sheep as a reference for free-ranging bighorns is not well substantiated and use of non standard samples such as serum vs organ values further complicate interpretation. Low selenium levels in some bighorn populations were associated with populations in long-term decline but were also associated with other herd health challenges (Hnilicka 2002, Lemke and Schwantje 2005). Similar situations have not been detected in Alberta (Flueck et al. 2012). Although serum selenium levels in some populations in west-central Alberta are slightly elevated they appear to be within the tolerance range that precludes acute toxic effects (MacCallum 2006) but the occurrence or effects of possible subtoxic effects remain unknown and are very difficult to document, as with many trace minerals.

Figure 53. Band of rams on reclaimed habitat of Cadomin Coal Mine. Photo Source: https://guinnoutfitters.com/209/

Figure 54. Left. Location of coal mine footprints in the Upper Macleod River watershed of west central Alberta. Source: Alces Online. Right. Satellite image of active and reclaimed portions of the Luscar coal mine. Source: Alces Online

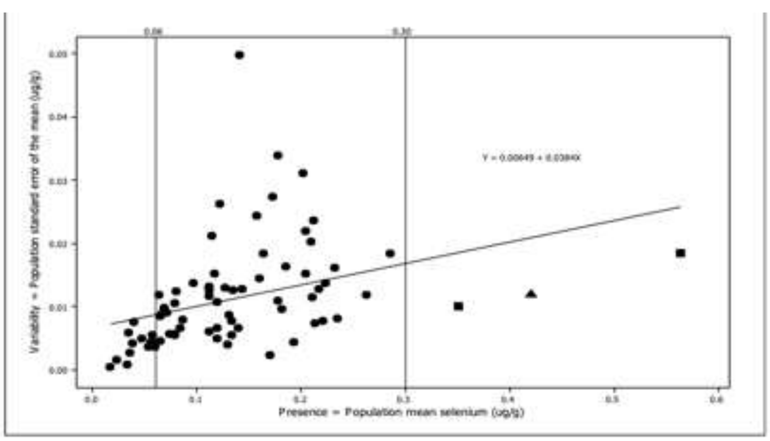


■ = unsupplemented; ■ = coal mine; ▲ = purposely supplemented

Probability of a supplemented BHS population occurring among 21 unsupplemented BHS populations:

L&GR (n=21, t= -31.1, p<0.001); SRC (n= 21, t= -15.79, p< 0.001); purposely supplemented (n= 21, t= -20.8, p<0.001)

Figure 55. Comparison of selenium concentration in blood from bighorn sheep in locations with and without access to supplemented vegetation that is known to be high in selenium.



● = unsupplemented; ■ = coal mine; ▲ = purposely supplemented

Figure 56. Identification of a safe operating space (0.06-0.30 ug/g) for selenium in western North America based on 72 population of seven species. Source: Kneteman, 2016.

Coal Mining, Explosives, Nitrogen, and Water Quality

To gain access to coal seams, mining companies use explosive to mobilize overburden rock, which is subsequently removed to expose the underlying coal. This overburden rock is deposited in waste rock dumps. A generic video representation of this explosion process in coal mining can be viewed at https://www.youtube.com/watch?v=xaMSgXi4P0I. These explosives generally involve high concentrations of nitrate (generally in the form of ammonium nitrate but also sodium nitrate and calcium nitrate), which can have significant adverse impacts on both surface and subsurface[131] hydrology. The most studied adverse effects of nitrate loading downstream of coal mines are altered trophic systems (food webs), algal blooms (eutrophication), and human health issues. Most of the nitrate entering aquatic systems originates from *spillage, during transportation or changing, leaching of the explosive in wet blastholes or undetonated explosive in the broken rock after the blast* (direct quote)[132]. Measurement of nitrate immediately below coal mines in the Coal Branch region of west-central Alberta found that nitrate concentrations were ~20 times higher than streams immediately upstream of coal mines (Figure 46). Changes in nitrate concentrations at sites on West Line Creek downstream of Teck's Line Creek Coal mine increased significantly following the construction of the coal mine (Figure 57, Figure 58). With increasing knowledge about how coal explosives can reduce downstream water quality, some mining companies are exploring new formulations of nitrate[133,134].

Although the dynamics of nitrogen emissions from coal mining were not examined in this study, this issue is an important one and deserving of detailed examination.

Figure 57. *The Elkview coal mine near Sparwood, B.C. is pictured in Teck Resources Ltd. photo.* This image illustrates the terracing that has occurred after overburden is removed by explosives.

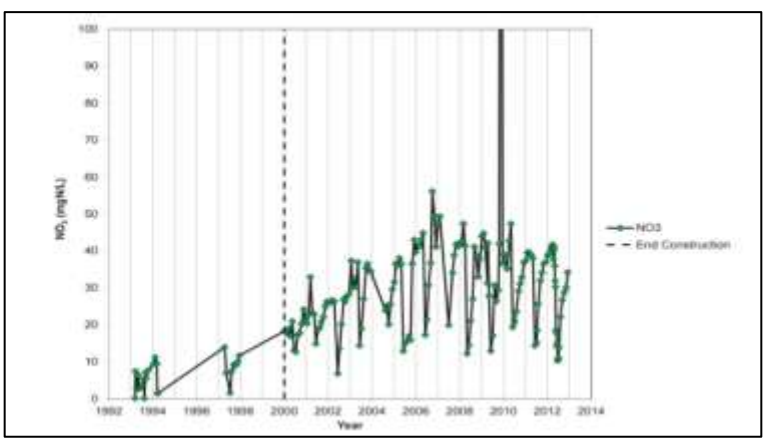


Figure 58. Changes in measured nitrate concentrations (mg N/liter) in West Line Creek (WLC) following the construction of the Line Creek Coal Mine. Source: Teck Coal, https://mail.google.com/mail/u/0/#inbox/KtbxLxghjzhTGcVrIBvXClVxlJgKJltXlg?projector=1&messagePartId=0.1

The Issue of Mine Reclamation

The Government of Alberta's mine reclamation regulations[135] indicate that abandoned mine sites and associated industrial footprints must be reclaimed to a "capacity" that is similar to that which existed in the pre-mine landscape. The vagueness of the word "capacity" is problematic as it enables immense flexibility and operational license by mine owners in how they reclaim their mining projects. Little or no description is provided that identifies specific thresholds of ecological function that pertain to water quality, water quantity, surface and subsurface hydrology, or fish habitat and population. Actual reclamation performance can be viewed as a spectrum, with reclamation efforts varying between those that spend minimal time and funds and accomplish little to ones that succeed in recreating an acceptable level of form and function of the post-mine landscape.

As a general rule, reclamation performance is positively related to cost, with expenditures varying from 0$/ha (basically walk away) to efforts that can exceed $200,000/ha. Historical assessment of post-reclaimed landscapes tells us that reconstructing an ecologically functional post-mine landscape requires a careful integration of relevant disciplines (physics, chemistry, soils, micro-biology, climate, hydrology, plant community dynamics, plant/animal interactions). This is important and difficult work that requires comprehensive planning and numerous years to get it right. The Landform Design Institute[136] describes both the historical challenges and opportunities associated with mine reclamation performance. All too often, reclamation efforts are confined to a quick "sculpting" of the post-mine landscape and establishment of green vegetation. Whereas these reclamation elements are important, and can create a non-offensive visual experience to the lay public, they offer more form than function, and may do little to ensure that the underlying hydrology of the post-mine landscape deliver sustainable patterns of water quantity and quality. Without proper hydrological function (both quantity and quality) on post-mined landscapes, it is unlikely that other elements (plant and wildlife dynamics) will be sustainable.

The ORW has a history of surface mining of coal (see Appendix section on Legacy Mines). Today, it is clear that mine reclamation efforts of these legacy mines varied from none to minimal. Clearly there can exist a difference between a government's current regulatory wording and the actual historical performance of reclamation efforts. A key reason that mine reclamation efforts fail is lack of legally required funds dedicated to reclamation. The amount of bonds secured from mine owners by the government is typically a very small fraction of the actual reclamation costs[137], and often the reclamation budget itself is a significant under-estimate of the funds required to complete a functioning post-mine landscape. According to McKenna Geotechnical (pers. comm, May, 2021), companies typically under-estimate actual reclamation costs by 2 to 10 fold. Furthermore, bonds secured by governments seldom exceed ~10% of their reclamation cost estimates. As such, the amount of bond funds typically secured is generally about 1% of the actual costs needed for adequate reclamation. Complicating the matter further, it is not uncommon for parent mine companies at their later stages of economic lifespan to become insolvent or sell their assets (and liabilities) to junior companies that subsequently become bankrupt (McKenna, pers. comm). In these cases, abandoned mine sites are not reclaimed, or the costs are fully born by the public.

Albertans are now beginning to better understand the magnitude of reclamation liability that attends the provincial hydrocarbon sector. Numerous studies have highlighted these liabilities in the bitumen, and oil and gas sectors[138]. It is increasingly clear that whereas the hydrocarbon sector has created significant economic benefits (employment, royalties), the magnitude of reclamation liabilities (legacy of industrial footprint, contaminated surface and subsurface water, loss of natural plant communities) are also substantial. Given the challenges in securing adequate funds and regulations to ensure good reclamation within the bitumen, oil, and gas sectors, it is equally reasonable to expect significant future reclamation liabilities in the coal sector.

In the absence of detailed mine closure plans for each of the eight prospective mines examined in this study, we have selected a reclamation scenario based on known reclamation trajectories observed in Teck's coal leases in the Elk Valley during the past 50 years[139] (Figure 59). Although our simulations do examine the areal extent of mine reclamation, it is beyond the scope of this project to examine site-specific dynamics of hydrological function associated with reclamation techniques.

Our study attempts to estimate a range of mine reclamation costs associated with the coal mines in the ORW headwaters. To do so, we have reached out to McKenna Geotechnical, as this company has worked for both proponents and opponents of the ORW coal mines and has significant expertise in this arena. Their analyses

suggest that actual costs can range from $25K/ha (minimal; most simple sites or most rudimentary efforts), $100K (medium; likely to meet regulatory standards) to $175K (high; more typical of challenging topographic sites). Low values typically reflect minimal reclamation efforts and low standards on simple sites; high costs generally reflect more comprehensive efforts on more complex mountainous landscapes. These costs reflect a variety of key reclamation components (re-grading, cover-soils, removal of infrastructure, vegetation seeding and planting, lightly armored drainage channels, and monitoring for 10 years). These costs do not, however, incorporate important costs associated with the reconstruction of surface water channels ($2-4K/ha), soft tailings ($200-1,500K/ha), water treatment plants (generally $30-100 M each), or other assorted components.

A consideration of mine reclamation dynamics in Alberta, focusing on wetland systems, was completed by Foote[140] (2012). He estimates that 6% of net profits would need to be directed to reclamation if adequate wetland dynamics are to be restored, that significant uncertainty attends mine reclamation efforts, and lengthy time periods (centuries) are required to assess actual reclamation performance.

Alberta's Mine Financial Security Program has been determined as deficient by a 2015 Alberta's Auditor General report[141]. In a new report issued 10 June 2021, the Auditor General found that the Government has failed to rectify these problems in the intervening six years. Moreover, even though significant footprint is associated with the exploration phase of coal mining, the Government of Alberta does not require any securities bonds for exploration activities of coal companies.

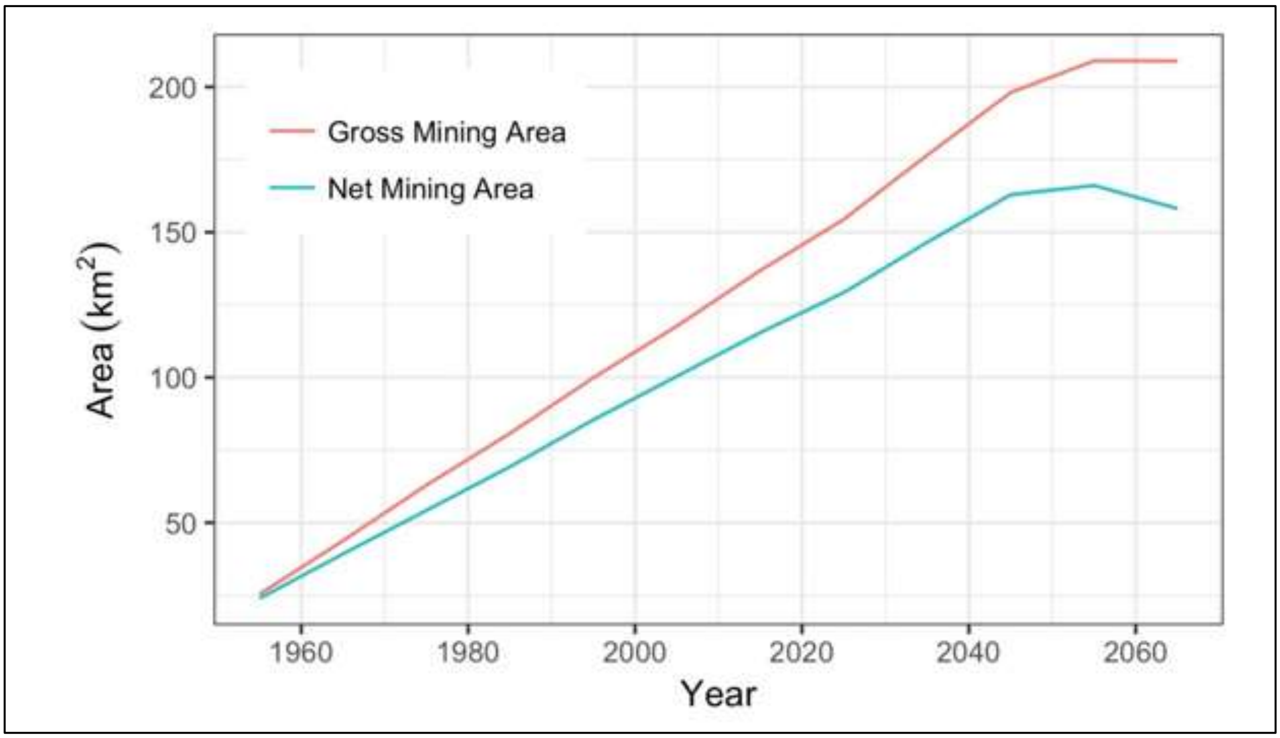


Figure 59. Temporal comparison of net coal mining (taking reclamation into account) and gross coal mining footprint area in the Elk Valley. Source: https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/cumulative-effects/draft_elk_valley_ceam_12122018.pdf. The difference between the gross mining area (red line) and the net mining area (blue line) reflects the ~25% of mining area that was reclaimed after 50 years of mining.

Tourism on the East Slopes

Tourism is an important component to Alberta's economy, contributing about $8.5 Billion/yr, supporting 19,000 businesses and responsible for over 127,000 jobs (Alberta Tourism, 2020). Although quantifying the precise fraction of this revenue and employment to the East Slopes is challenging, all Albertans understand the key role the East Slopes play to the overall economic viability of tourism and recreation. Alberta's East Slopes have been recognized by both the global *Greens Destination*[142] and the *Top 100 Sustainable Destination*[143],[144] initiatives for its significance to sustainable tourism.

A 2011 economic study completed by [Econometric Research Ltd]() on Kananaskis Country[145], a landscape very similar to the ORW headwaters examined in this report, contributes the following economic outputs (units refer to 2011) each year:

- 1,103,000 visits
- $202.5 M of value-added economic impact
- 3,023 full time equivalent jobs
- $125.4 M in wages and salaries
- $117.2 M in total tax revenue

It would be logical that the economic contributions of the ORW headwater landscape is similar to these values described above, or have the potential to generate these economic values, as demand for tourism and recreation based activities continue to grow in Alberta.

The draws for tourists are many-fold but include aesthetic appeal, the rugged Rockies, clean flowing rivers, and pristine lakes. Extensive coal mining is likely to imperil the attraction of Alberta's east slopes as a tourism destination. It is also likely that coal mining will stigmatize Alberta with an international reputation as a "bad player" on the climate change stage. While the list of countries banning or decommissioning coal mining continues to expand quickly, Alberta's current administration has the dubious distinction as a jurisdiction that has labelled coal mining as a key ingredient to its economic future.

Figure 60. Mountain biking is one of many different back-country and front-country forms of recreation and tourism. Source: To DoCanada;https://www.google.com/search?q=tourism+crowsnest+pass&rlz=1C5CHFA_enAU840AU840&sxsrf=ALeKk03yaua_zLGU4aciP3AL2Yn8JEZGBA:1623295658189&source=lnms&tbm=isch&sa=X&ved=2ahUKEwiM-cjIj4zxAhUJ-Z4KHV1XBKcQ_AUoAXoECAEQAw&biw=2097&bih=1231#imgrc=JLX_W-O1CuwztM

Coking Coal, Steel Production and the Push to Net Zero

Whereas Canada's federal and provincial governments have recognized the GHG-related importance of decommissioning coal plants that convert coal energy into electricity (thermal coal), there is much greater hesitancy to adopt a similar policy direction when it comes to metallurgical coal. Historically, the international demand for coking coal has been high (Figure 61, Figure 62), and the upstream production costs of coking coal are comparatively low if actual environmental costs are externalized. The coal sector is a powerful lobby[146], and has been effective at pressuring governments to continue to support coal production[147].

Alberta has large volumes of high quality, low-sulphur coal, so it is understandable that international capital is mobilized to develop these deposits in southwest Alberta and the adjacent Elk Valley in BC. A recurrent argument by the coal sector is that coking coal is the only viable option in the production of steel. A review of this argument indicates that viable alternative technologies to coal have emerged. The efficiencies of coal alternatives (such as blue or green hydrogen) in steel production processes will only become higher, and their costs lower, as these technologies benefit from additional research in this emerging technology[148].

Undeniably, coal mining is currently a cheap method for producing energy, as one is essentially digging existing energy out of the ground that was produced by millions of years of plant decomposition and compression. While renewable sources of energy (wind, solar, hydro) have been historically more costly as an energy source for production of hydrogen used in steel production, the cost gap is narrowing quickly[149]. When the true costs (inclusive of natural capital) of coal mining and combustion are examined, then coal becomes a more costly and less desirable alternative to emerging hydrogen technologies that are carbon free and becoming incrementally less expensive. A review of the issue of coking coal in the steel production process is examined in more detail by:

- https://wildsight.ca/2020/06/01/do-we-really-need-steelmaking-coal/
- https://www.letstalkaboutcoal.co.nz/future-of-coal/making-steel-without-coal/
- https://thenarwhal.ca/steel-coal-mining-hydrogen/

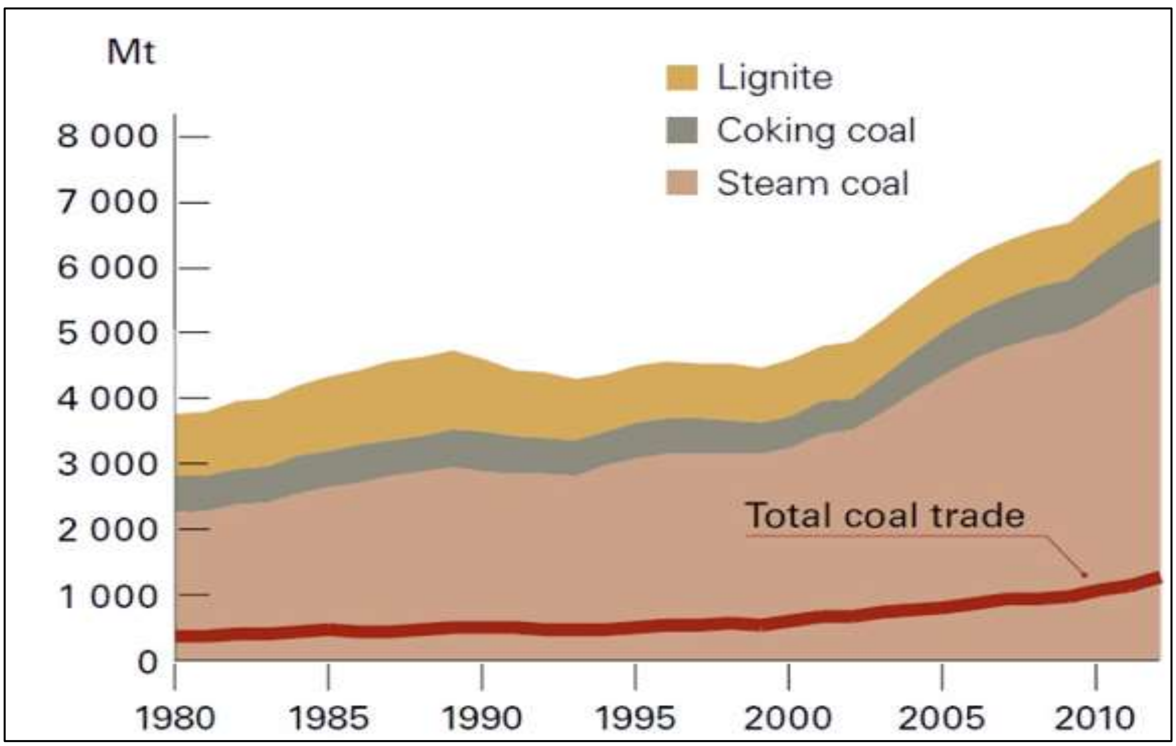


Figure 61. Historical global consumption of coal. Source: https://euracoal.files.wordpress.com/2014/09/ciae2013-fig7t1.png

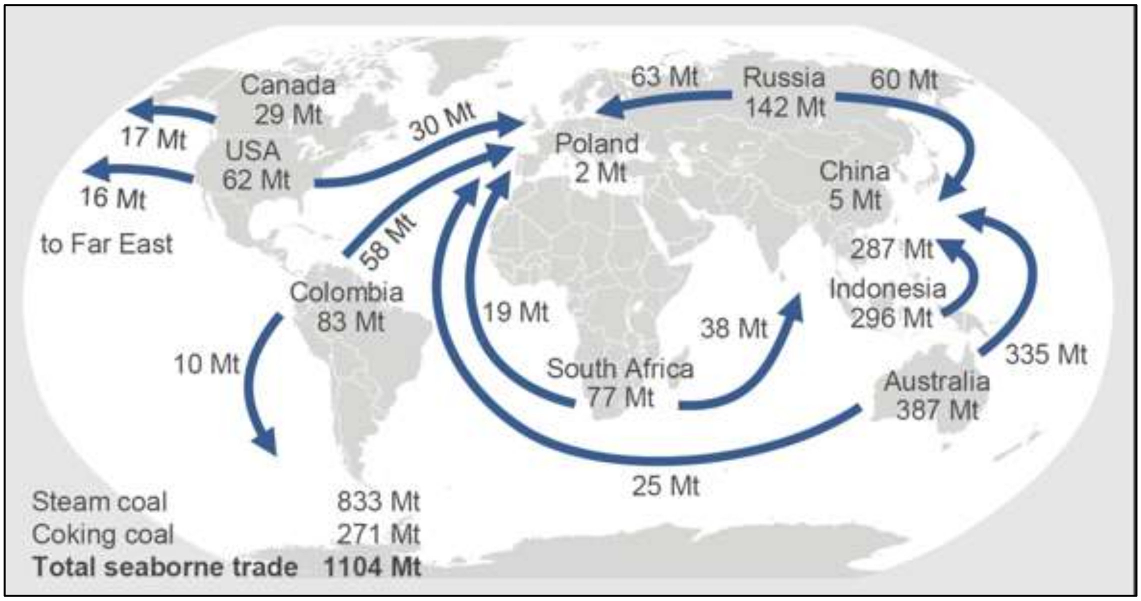


Figure 62. *World traded coal flows in 2015 (VDKi, 2016). Source:* https://euracoal.eu/coal/international-coal-trade/

The literature describing the adverse global consequences of GHG emissions from the coal, oil and gas sectors to climate change is rigorous and beyond scientific reproach[150]. During the past several decades, however, these findings have been vigorously denied by individuals and sectors promoting continued growth and investment in the conventional hydrocarbon sector. What is at stake on both sides of this argument is incalculably immense, so it is unsurprising that jurisdictions like Alberta whose economies are highly dependent on non-renewable oil and gas sectors are reluctant to embrace the transition to renewable energy supply chains.

Although the ultimate conclusion of this debate and necessary societal action is clear, the challenge confronting Alberta and Albertans is when and how to adopt broad policy actions that safeguard its own natural capital, reduce its contributions to global emissions, and position it to benefit economically from the renewable technologies and land uses that have now begun to shape global economies.

At the time that the Alberta Government is actively promoting a new era in East Slopes coal mining, the International Energy Agency (IEA) has just released its NET Zero by 2050. A Roadmap for the Global Energy Sector (2021). Their vision entails a complete transformation of the global energy system, one where investment in conventional coal, oil and gas projects is rapidly abandoned and directed to renewable energy systems. In their Net Zero (NZ) scenario, the IEA report lays out the future trajectory of each element in the energy mix. Their summary comments on the future of coal are:

No new coal mines or extensions of existing ones are needed in the NZE (net zero emission) as coal demand declines precipitously. Demand for coking coal falls at a slightly slower rate than for steam coal, but existing sources of production are sufficient to cover demand through to 2050. Such a decline in coal demand would have major consequences for employment in coal mining regions (see Chapter 4). There is a slowdown in the rate of decline in the 2040s as coal production facilities are increasingly equipped with CCUS (carbon capture, utilisation and storage): in the NZE, around 80% of coal produced in 2050 applies CCUS. Excerpt from Net Zero by 2050 (2021)

One week after the IEA announcement, the G7 (May, 2021)[151] committed to stop financing all overseas coal projects. Their communique includes the following:

"Consistent with this overall approach and recognising that continued global investment in unabated coal generation is incompatible with keeping 1.5C within reach, we stress that international investments in unabated coal must stop now and commit to take concrete steps towards an absolute end to new direct government support for unabated international thermal coal power generation by the end of 2021, including through Official Development Assistance, export finance, investment, and financial and trade promotion support."

Most recently in June 2021, the Global Energy Monitor published a report entitled Deep Trouble, Tracking Global Coal Mine Proposals., which documents that an additional 2.3 BTA (Billion Tonne/Year) of coal production is currently under development globally (Figure 63). The United Nations and numerous other research organizations have computed that global coal production would need to decline by ~11%/annually if a 1.5 °C threshold is not to be breached[152]. This report also notes that Canada has 33 coal mines currently in the pre-construction phase and 6 in construction.

Given the evolving state of knowledge on the climate change/GHG crisis, promoting a new coal trajectory in Alberta's East Slopes would have been somewhat understandable in the 1950s, highly questionable in the 1990s, but incomprehensible and indefensible today.

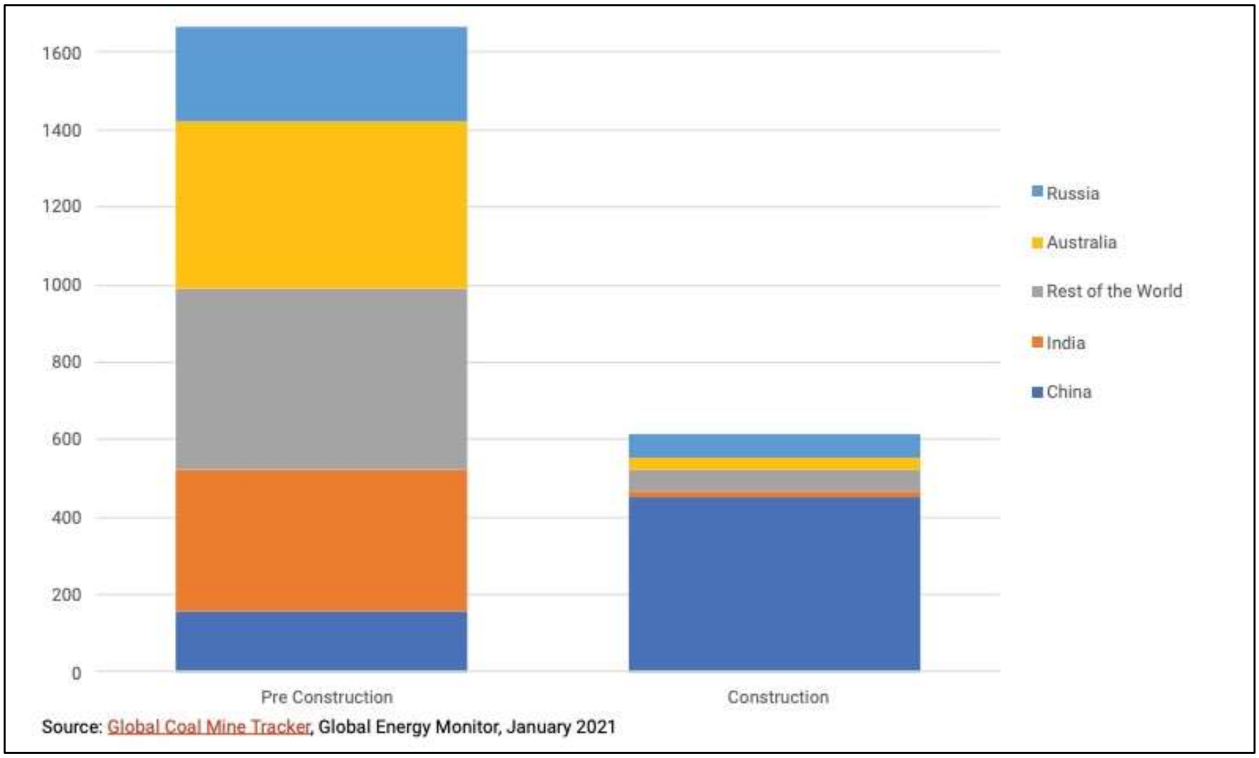


Figure 63. Coal mining capacity under development (MTA). Source: Global Coal Mine Tracker. https://globalenergymonitor.org/wp-content/uploads/2021/05/CoalMines_2021_r4.pdf

Conducting Proper Cumulative Effects Assessments

Although the structure and methodologies of proper cumulative effects assessments have been widely described[153], they are seldom endorsed or conducted in Canada by provincial or federal governments/agencies charged with sustainable resource mandates[74,154]. A recent review by the Council of Canadian Academies[155] entitled Greater Than the Sum of Its Parts: Toward Integrated Natural Resource Management in Canada, highlights the need for a fundamentally new approach to examining sustainability on regional landscape shaped by multiple overlapping land uses. There are several reasons why government and industry resist following the well understood principles of cumulative effects assessments, but arguably the most important reason is fear that its methodological outcome would reveal the magnitude of environmental liabilities, and that this knowledge might interfere with capital investment or economic growth. Because of persistent tendencies to externalize the economic value of natural capital, many in government and industry struggle to understand that sustainable management of ecosystems is fundamental to securing long-term economic prosperity. This puts them at odds with embracing the principles of rigorous cumulative effects assessments.

A timely example of the lack of a proper cumulative effects ideology is how the Government of Alberta and the coal sector has framed the conversation about the prospects for extensive coal mining in Alberta's East Slopes. Four of the hallmarks of proper cumulative effects assessments relate to systems integration, multi-stakeholder participation, spatial scale, and temporal scale. If assessments of coal mining do not adequately address all of these interacting benchmarks, then there cannot be an informed conversation about both the benefits and liabilities of coal mining. If these principles are ignored, then the landscapes of the East Slopes, and Albertans, are put at risk.

Systems Integration. The watersheds of the East Slopes, such as the ORW, are biophysical systems, complete with physical, biotic, human, and landuse components and their myriad inter-actions. From a human perspective, we often think of these systems through the lens of social, economic, and environmental performance. These components interact, in ways we understand and in ways we do not. Altering one or more of the system components will invariably cause others to adjust and respond. There are many hundreds of components to the ORW system and many tens of thousands of interactions. To date, a systems-based approach to examining coal mining in the East Slopes against the full suite of land uses and natural disturbance regimes has not been requested or completed. Given the important role that headwater basins play to system elements (water quantity, water quality, carbon movement, fish dynamics, wildlife corridors) it is certain that coal mining will affect many, if not most, components of the ORW system that lie downstream from mines. To date, the materials submitted as part of the Grassy Mountain EIA adopt a silo approach that does not reflect an integrated system. As such, it is not possible to understand how coal mining is likely to interact with other land uses (irrigation, livestock, recreation, residential, forestry), and key ecosystem dynamics that involve air quality, soils, carbon pools, water, and biodiversity.

Multi-Stakeholder Inclusivity

Cumulative effects assessment recognize and incorporate all land uses (land users) affecting a regional watershed, and as such all stakeholder groups need to be part of the discussion that identifies performance indicators (social, economic, environmental), identifies scenarios to be explored, and informs relevant spatial and temporal scales of the project. The Government of Alberta failed to recognize this key principle, and the loud response from awakened Albertans subsequently catalyzed a consultation process in the wake of this anger. The existing consultation process is not in any way a cumulative effects project, but does hopefully set the stage for initiating one.

Meaningful Spatial Scale

What is abundantly clear is that the current administration of the Government of Alberta, the Canadian Coal Association, and prospective coal mining companies, wish to see a large coal mining trajectory in Alberta's East Slopes. This spatial magnitude has been well documented through an examination of existing leases, existing coal mining proposals, and the numerous websites of coal mine companies seeking investment capital. Despite this information, the Government of Alberta has to date confined its regulatory processes to a single coal mine: Grassy Mountain. This narrow, myopic and misleading focus precludes all stakeholders from a robust opportunity to

understand the full suite of benefits and liabilities that would attend such a new and expansive land use trajectory in the East Slopes.

Meaningful Temporal Scale

The appropriate "time" scale for robust cumulative effects assessment is one that allows the current and foreseeable projects to unfold in relevant temporal and spatial scale. So let's call it for what it is. The coal proponents (Government of Alberta, Canadian Coal Association, investors) wish to develop and implement a new and expansive coal play along Alberta's East Slopes that could produce more than 1 Billion tonne of coal, create thousands of jobs, and generate large profits to investors. But in doing so it will also transform hundreds of square kilometers of natural landscape, consume significant volumes of water, emit large volumes of GHG, and contribute toxins such as selenium and calcite into the waterways that provide the lifeblood to all downstream land uses. This is the classic benefit and liability dynamic that attend all land use considerations. Only by exploring the fullest vision (in both time and space) of this coal mining concept can Albertans hope to understand what is at stake.

The Bottom Line

The Government of Alberta has devised a new and regional land use plan based on large-scale coal mining in Alberta's East Slopes. Senior government leadership has engaged with investors from Australia (and elsewhere), who have, in turn, focused their interactions, to date, with Alberta Energy and selected communities in the Crowsnest Pass. But what is at stake is not confined to the "Pass". Both the benefits (jobs, royalties, rents) and liabilities (loss of watersheds and biodiversity, GHG emissions, water and air pollution) will affect all Albertans, not only today but for innumerable generations to come. The decisions of the provincial and federal governments on this key issue will also say much to a global audience and our international visitors about what is important to this province and country. This is a decision worth getting right. Like most difficult decisions, it deserves and demands an appropriate arena for meaningful consultation.

Modelling Methodology

A detailed description of the methods used for assessing water quality and quantity are provided by Chernos et al. (2021).

Key Performance Metrics

Following discussions with LLG, it was agreed that this project would generate a set of "what-if" simulations examining different future levels of coal production, climate change, and water emission toxins (selenium) capture rates. For each of these simulations, a set of outputs would be generated for each of the key performance metrics listed below (Table 4). These performance indicators are believed to provide insight into the potential consequences of coal mining in watershed integrity of the ORW.

Table 4. Key performance indicators examined in this study.

Performance Indicator	*Unit*
• Water Quantity	
○ Surface Water Discharge	m^3/yr
○ Total Water Use	m^3/yr
○ Water Remaining for Instream Flow	m^3/yr
• Water Quality	
○ Total Selenium Production (load)	kg
○ Dissolved Selenium Concentration	ug/liter
• Climate Change and GHGs	
○ $C0_2e$	tonne/year
• Landscape Metrics	
○ Loss of Stream and Riparian Area	ha

Incorporating the Elk Valley into our project methodology. Is coal mining there a reasonable reference site for the ORW?

The coal mines proposed for the headwaters of the ORW are precisely that – proposals. They do not yet exist as active mine sites and these "proposals" do not currently yield "local" datasets that scientists can study. As such, some key pieces of information on coal geology and exploration, waste rock dynamics, mine development and reclamation schedules, water demand, and coal-related emissions (Se, PM2.5, …) must be inferred from other comparable data sources. As part of Alberta's environmental impact assessment process[156], most coal mining proponents offer insights into the expected metrics for their projects. These data sources are most helpful and have been extensively adopted in this study. Examples would be the documents submitted as part of the Grassy Mountain Coal Project[157] and the Tent Mountain Coal Project[158].

The ORW coal study is fortunate in that the Elk Valley is immediately west (10-20 km) and has been extensively mined for coking coal during the past several decades (Figure 10,Figure 64, Figure 65). In the Elk Valley, annual coal production is approx. 30-35 MTA and has been estimated at a cumulative (since 1890) volume of 830 million tonne[159]. Estimated total area disturbed by coal mining (as of 2020) is ~14,000 ha[160] (Figure 65). It is interesting that the MTA (23.95 MTA), cumulative volume (693.8 MT), and area of disturbance (9,411 ha) proposed by the eight combined ORW coal projects examined in the ORW study are very similar to the Elk Valley analog immediately to the west. In comparison, the coal simulation trajectory in this study creates a footprint of 65% and a volume 83.5% of that in the Elk Valley over a similar 5 decade interval.

Where information on proposed ORW coal projects do not exist, the historical information gained in the Elk Valley is considered a robust reference source (Figure 64). The coal resources of both of these regions share the same geologic origin (Mist Mountain Formation). The technical value of comparing coking coal dynamics in SE BC and SW AB is emphasized by Atrum Coal in their online publications[161].

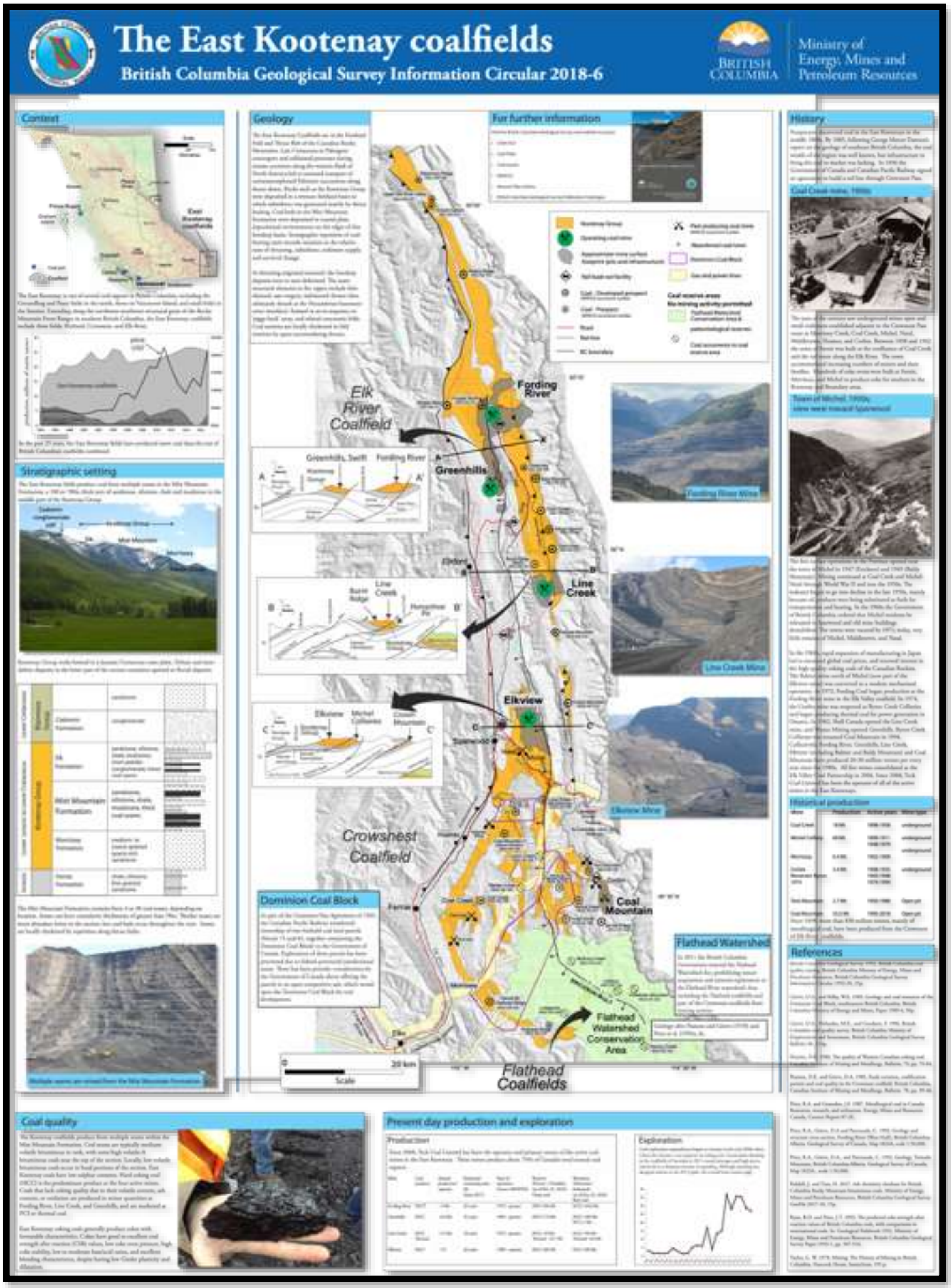


Figure 64. Profile of coal mining in Elk Valley. Source: http://cmscontent.nrs.gov.bc.ca/geoscience/PublicationCatalogue/InformationCircular/BCGS_IC2018-06.pdf

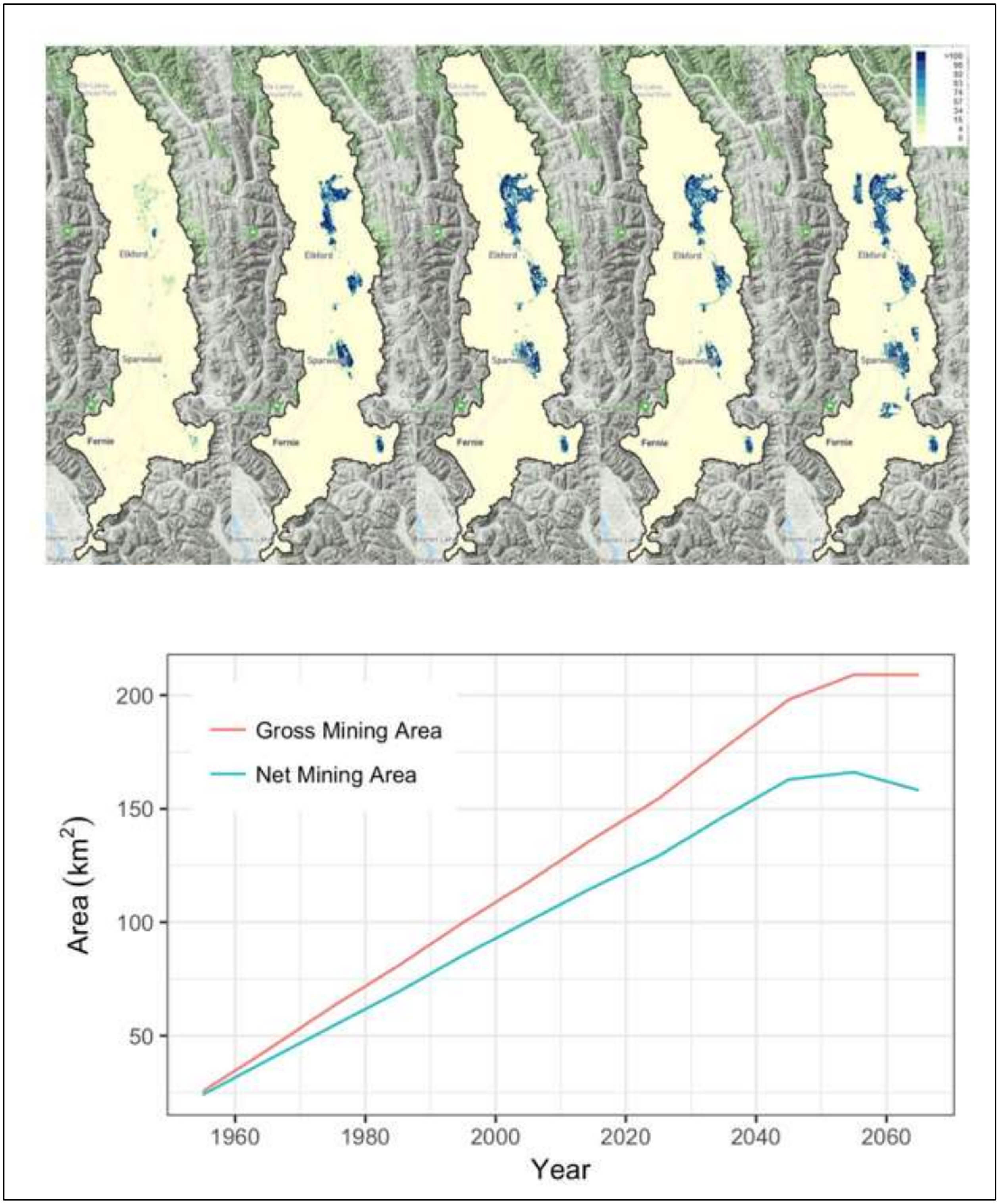


Figure 65. (Upper) Coal mine area in the Elk Valley during (left to right) for 1950, current, and Reference, Minimum, and Maximum scenarios in 2065. (Bottom) Temporal comparison of net coal mining (taking reclamation into account) and gross coal mining footprint area in the Elk Valley. Source: https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/cumulative-effects/draft_elk_valley_ceam_12122018.pdf. The difference between the gross mining area (red line) and the net mining area (blue line) reflects the ~25% of mining area that was reclaimed after 50 years of mining.

Simulation Methodology

The simulations contained in this study (Table 5) focus primarily on coal mining but do so while examining other dynamics (climate change, other land uses, water supply, water demand) important to the ORW itself and its residents.

This project reflects a simulation methodology that incorporates a quantitative understanding of the climate and land use history of the ORW, and then projects the landscape and its dynamics forward under different combinations of coal mining, land use and climate. By exploring different combinations and levels of these factors (i.e., sensitivity analyses), it is possible to gain insights into the relative probability of meeting management objectives or encountering issues that prevent obtaining desired futures.

The matrix table below visualizes the scenarios completed in this project.

- In the 1st set (light green) of scenarios (1-3), both climate and non-coal land uses are held constant (as per current conditions) and only coal mining is allowed to change.
- In the 2nd set (orange) of scenarios (4-6), both climate and coal mining are allowed to change.

Scenario Definitions

Within each simulation set, a "low" coal mining simulation occurred where no new coal production occurs. The second simulation level is defined as "medium" and included the activities of Grassy Mountain and Tent Mountain coal projects. This medium scenario produces 106.9 MT of coal over the 50-year simulation period with a maximum annual rate of 5.875 MTA. The last simulation level is referred to as "high", and included all of the major prospective projects (Riversdale's Grassy Mtn, Montem's Tent Mountain, Atrum's Elan South and Isolation South, Montem's Chinook Vicary, 4-Stack, and Isola). The High scenario produces 693.8 MT of coal over the 50-year simulation period with a maximum annual rate of 23.95 MTA.

Table 5. Matrix of "what-if" simulations involving coal mining, climate change and land use change, examined in this study. Coal MTA values reflect maximum annual values.

Scenarios	Coal Trajectory	Climate Change
Scenario 1	Low (None)	As per Current
Scenario 2	Medium (5.875 MTA; Grassy & Tent)	As per Current
Scenario 3	High (~23.95 MTA; 8 mines)	As per Current
Scenario 4	Low (None)	Climate Change (RCP 4.5)
Scenario 5	Medium (5.875 MTA; Grassy & Tent)	Climate Change (RCP 4.5)
Scenario 6	High (~23.95 MTA; 8 mines)	Climate Change (RCP 4.5)

Selecting Prospective Coal Mines for Simulation

This study examines the potential effects of 8 separate proposed coal mining projects on key performance indicators. Two of these coal projects (Grassy Mountain, Tent Mountain) are further along in terms of their regulatory approval, whereas the other 6 exist at an earlier stage in their regulatory assessment. Existing details on these projects is summarized in Table 6. It is important to understand that we are using the best available information (submissions to Government of Alberta, analyses by consultants, investor reports), to simulate the key elements of these mines (location, area, production, reclamation, waste rock production). We do not suggest that we are simulating all aspects of the mine correctly, or that these individual projects will ever come to exist. Our intent is to use these prospective mines as a reasonable template to illustrate both the benefits and liabilities that would attend such a prospective coal mining trajectory.

Table 6. Summary of key coal mining project metrics.

Prospective Coal Project Name	Low Growth Scernario	Medium Growth Scenario	High Growth Scenario	Coal Project Lease Area (ha)	Cumulative Area of Disturbance (ha)	Proposed Lifespan yrs	Ave Annual Coal Production (tonne/yr)	Maximum Annual Coal Production (tonne/yr)	Cumulative Coal Production (MT)	Proven or Indicated Coal Resources (tonnes)
Grassy Mountain Coal Project		x	x	8,330	1,244	25	4,026,609	4,706,000	92,612,000	1,125,000,000
Tent Mountain Project		x	x	1,931	364	14	1,020,639	1,198,600	14,288,950	22,000,000
Elan South Coal Project			x	13,000	1,261	22	3,997,701	5,293,179	91,947,116	47,000,000
Isolation South Coal Project			x	6,239	1,278	21	5,528,137	6,000,000	127,147,151	112,000,000
Cabin Ridge Project Ltd			x	5,000	1,276	23	3,997,701	5,293,179	91,947,116	100,000,000
Isola Coal Project			x	4,832	1,354	25	3,997,701	5,293,179	91,947,116	100,000,000
4-Stack Coal Project			x	1,965	1,235	25	3,997,701	5,293,179	91,947,116	100,000,000
Chinook (Vicary) Coal Project			x	10,000	1,334	25	3,997,701	5,293,179	91,947,116	149,000,000
Totals				51,297	9,346		13,875,674	23,948,137	693,783,680	1,755,000,000

Time Frame

The time frame (future simulation period) for this project is 50 years. This period is considered an appropriate temporal scale to assess the incremental cumulative effects of a coal mining and subsequent reclamation trajectory. It also reflects the approximate elapsed time since the onset of coal mining in the Elk Valley immediately to the west of our study area.

Final Spatial Delineation of Surface Coal Mines for Simulations

Based on best available information on coal lease boundaries, coal project boundaries, coal mine proposals, underlying coal deposits, and coal test bore locations, the IEG team (see Chernos et al., 2021) delineated coal mining activity regions (Figure 66) that are used in this project for simulating "plausible" trajectories for production of coal (Figure 80, Figure 81) and waste rock (Figure 82, Figure 83).

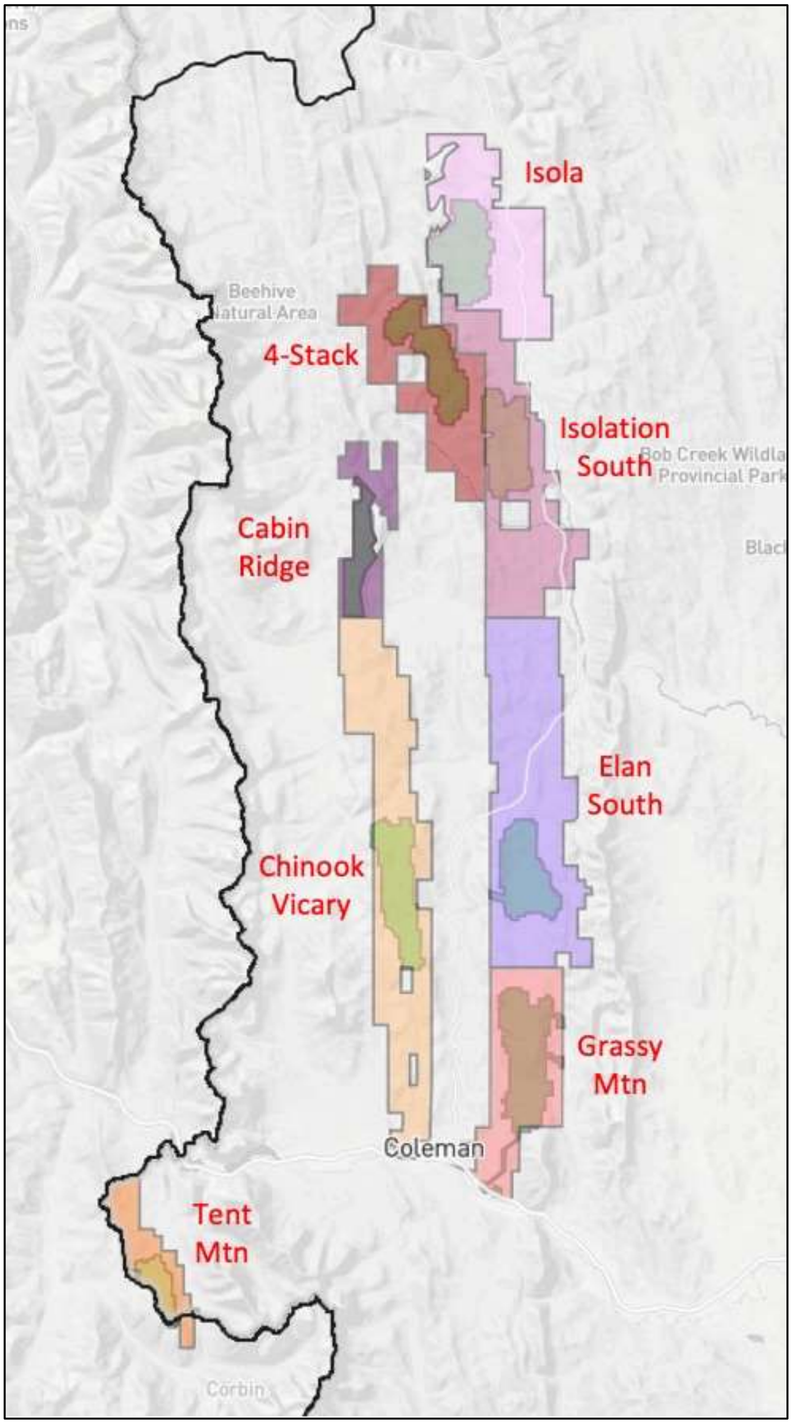


Figure 66. Boundaries of coal mine leases (exterior polygons) and surface activities (interior polygons) in the headwaters of the ORW.

Modelling Results

How do key indicators respond to coal mining?

In the low coal mine development scenario, no coal mines proceeded and as such there are no coal-related metrics to present. Under the medium coal development scenario, only the Grassy Mtn and Tent Mtn projects are allowed to proceed to operational status. In the high coal development scenario, all 8 prospective mine projects (Grassy Mtn, Tent Mtn, Elan South, Isolation South, Cabin Ridge, 4-Stack, Isola, and Chinook/Vicary) were simulated.

The spatial representation of coal mines under medium and high growth trajectories are mapped at 10 year intervals (Figure 68 - Figure 78). Over the full 50 year simulation, the average annual (and maximum annual) and cumulative values for each of land development area (ha), coal production (clean metric tonne), waste rock deposition volume (m^3), selenium production (grams), water use (m^3), reclaimed area (ha), reclaimed area liability ($),and CO_2e emission (tonne) are provided in tabular (Table 7) and graphic output (Figure 79 - Figure 101).

Medium Coal Development Scenario (Grassy and Tent Mountains)

By year 50 (2072), 1,608 ha (16.08 km^2) will be disturbed by active mining pit and waste rock deposition, which will result in the production of 106.9 M tonne of clean coal, and a total of 1.0 B tonne of waste rock that is moved and deposited. In total, ~1.2 km^3 (cubic kilometers) of material (coal and overburden) will be moved during this 50 year simulation. Almost all area disturbed is currently natural habitat types. As such, all or nearly all of stream and riparian habitat within the mine boundary will be destroyed or transformed by mine activities. These features will be lost for most of the 5 decade period of the simulation. Assuming surface drainage is reconstructed on these mine sites to current regulatory standards, their functional ecosystem value remains unproven. A total of 103 tonne of selenium will be generated by these two mines over the 50 year simulation. This represents an average of 2.074 tonne/year, respectively. Water use is estimated at 0.436 M (average annual) and 21.8 M m^3, cumulatively. The maximum annual use of water is 1.2 M m^3/yr. The fraction of local annual water yield consumed by coal mining (gross water allocation) is estimated to exceed 40% (for example, Blairmore Creek) of seasonal flow during late summer and early winter months.

Greenhouse gas emissions (full life cycle of CO2e) related to these mines is estimated at 293 M tonne cumulatively and an average annual emission of 5.88 M tonne/year (full life cycle).

By the end of the 50 year simulation, approximately 402 ha (25%) of the total disturbed area will be reclaimed to vegetative cover. The total reclamation cost over the 50 years is estimated at $0.81 M/yr (cumulative of $40.2 M) but 75% will remain unreclaimed at year 50 (2072), which represents a further reclamation liability of $120.6 Million.

The simulated concentration of dissolved selenium (ug/liter) for selected downstream locations are shown in Figure 116 and Figure 117. At the headwaters proximal to coal mines, selenium concentrations are comparatively high and frequently exceed health thresholds during late summer/early winter months and particularly during those years of low precipitation. Selenium concentration is incrementally reduced with distance downstream from the mine sites as additional water volume from unaffected basins dilute the selenium. Conditions most conducive to selenium exceedances occur during winter months during years of low precipitation. As such, climate change scenarios that contribute to higher frequency and magnitude of drought years are likely to exacerbate issues related to selenium toxicity.

The water use by coal mines is small in comparison to irrigation demands, but can represent as much as 5% of the annual water budget for the cattle population within the ORW. Existing water use in the ORW is approaching maximum allocations limits and as such additional water demands of coal mining contribute to less future flexibility, particularly when climate change scenarios are considered and if existing land uses chose to expand.

High Coal Development Scenario (all 8 coal mine projects are activated)

By year 50 (2072), 9,411 ha will be disturbed by active mining pit and waste rock deposition, which will result in the production of 693.8 M tonne of clean coal, and a total of 6,026.7 M tonne of waste rock that is moved and deposited. In total, ~6.7 km^3 of material (coal and overburden) will be moved during this 50 year simulation. Almost all area disturbed is currently natural habitat types. As such, all or nearly all of stream and riparian habitat within the active mining boundaries of the eight mines will be destroyed or significantly altered. These features will be lost for most of the 5 decade period of the simulation. Assuming surface drainage is reconstructed on these mine sites, their functional ecosystem value remains unproven. A total of 281 tonne of selenium will be generated by these eight mines over the 50 year simulation. This represents an average of 5.618 tonne/year, respectively. The fraction of this gross production that is released into water will depend largely on how successful coal companies are in recovering or extracting selenium. Recovery fractions exceeding ~95% will be required to reliably keep selenium below current performance thresholds. Water use is estimated at 2.831 M m^3/yr (average annual) and 141.5 M m^3, cumulatively. The maximum annual allocated use of water is 4.89 M m^3/yr. The fraction of local water yield consumed by coal mining can be as high as 40% for seasonal stream flow at creeks such as Blairmore Creek immediately below the proposed coal mine.

Greenhouse gas emissions (full life cycle of CO_2e) related to these mines is estimated at 1,908 M tonne cumulatively and an average annual emission of 38.2 M tonne/year (full life cycle).

By the end of the 50 year simulation, approximately 2,405 ha (25%) of the total disturbed area will be reclaimed to vegetative cover. Reclamation costs average $4.7 M/yr, with a cumulative expenditure of $235.2 M, but 75% of the disturbed mine area will remain unreclaimed at year 50 (2072), which represents a further reclamation liability of $705.8 Million.

The simulated concentration of dissolved selenium (u/liter) for selected downstream locations are shown in Figure 116 and Figure 117. At the headwaters proximal to coal mines, selenium concentrations are comparatively high and are expected to consistently exceed health thresholds during the simulation period. Selenium concentrations are higher in the high growth scenario than in the medium growth scenario because of the greater total loading of selenium in the headwaters. Our results indicate that selenium concentration is incrementally reduced with distance downstream from the mine sites as additional water volume from unaffected basins dilute the selenium. In all cases, selenium concentrations are highest during dry years and those months where stream flow is lowest (late summer to early winter). Conditions most conducive to selenium exceedances occur during winter months during years of low precipitation. As such, climate change scenarios that contribute to higher frequency and magnitude of drought years are likely to exacerbate issues of selenium toxicity.

The water use by coal mines is small in comparison to irrigation demands but can represent as much as 15.7% of the annual water budget for the cattle population within the ORW.

Table 7. Average and cumulative values for key variables over the full 50 year simulation. Note: Production lifespan of individual mines are generally lower than the 50 year simulation. (Values in parentheses () reflect the maximum value for any simulation year)

Variable	Units	Low Development Scenario		High Development Scenario	
		Mean Annual Max annual in ()	Cumulative	Mean Annual Max annual in ()	Cumulative
Area Disturbed	ha	32.2 (137)	1,608.0	188.2 (326)	9,411.0
Coal Produced	M tonne	2.138 (5.875)	106.9	13.87 (23.95)	693.8
Waste Rock Deposition	M m^3	20.7 (66.3)	1,036	120.5 (204.3)	6,026.7
Selenium Production (loading)	kg	2,074 (2,802)	103,721	5,618.0 (10,598)	280,901.0
Gross Water Use by Coal Mines	M m^3	.436 (1.198)	21.8	2.831 (4.885))	141.531
Reclaimed Area	ha	8.0 (30.4)	402.0	48.0 (85.0)	2,405.0
Reclamation Cost Incurred	2021 M C$	.81 (3.0)	40.2	4.7 (8.0)	235.2
Reclamation Liability at Yr 50	2021 M $C	2.4 (11.9)	120.6	14.0 (25.5)	705.8
CO_2e Emissions (full life cycle)	M tonne	5.8 (16.16)	293.4	38.2 (65.8)	1,907.9

Spatial Mapping of Coal Mines

Medium Growth Scenario (Grassy and Tent Mountain Coal Projects)

In the medium coal development scenario, the initial coal mine footprint (from legacy mines of Grassy Mtn, Tent Mtn) of 6.84 km^2, grows to a maximum of ~23.01 km^2 by the end of 5 decades (Figure 67). The decade by decade trajectory of this development scenario is shown in Figure 68-Figure 71.

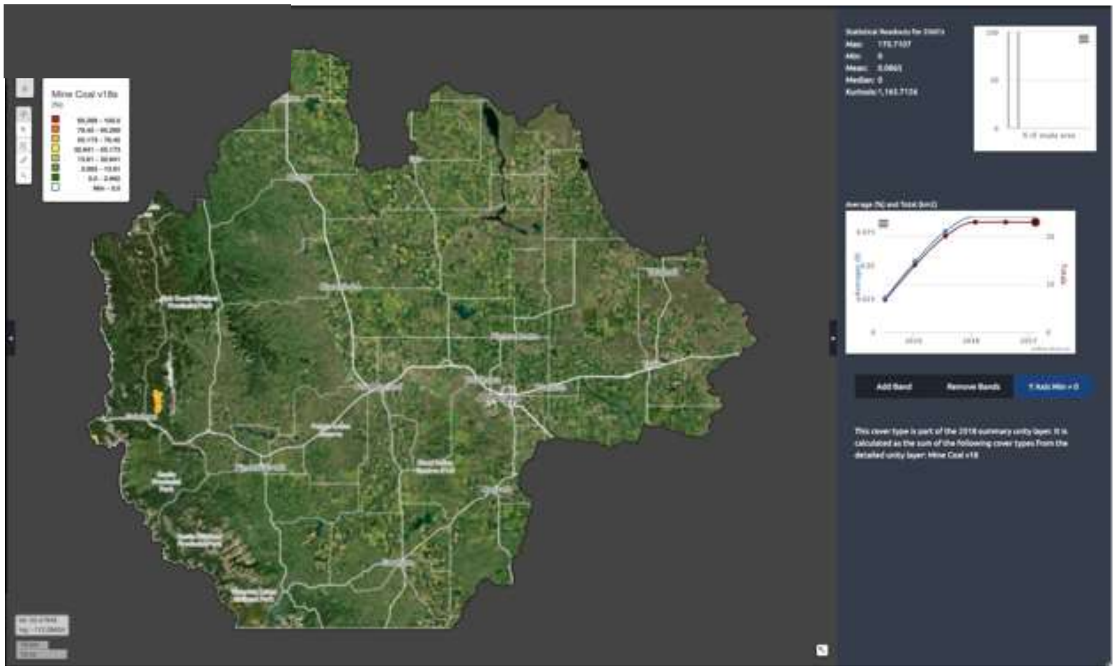


Figure 67. The ultimate cumulative footprint of the medium coal growth scenario that includes only the Grassy Mtn and Tent Mtn coal project proposals.

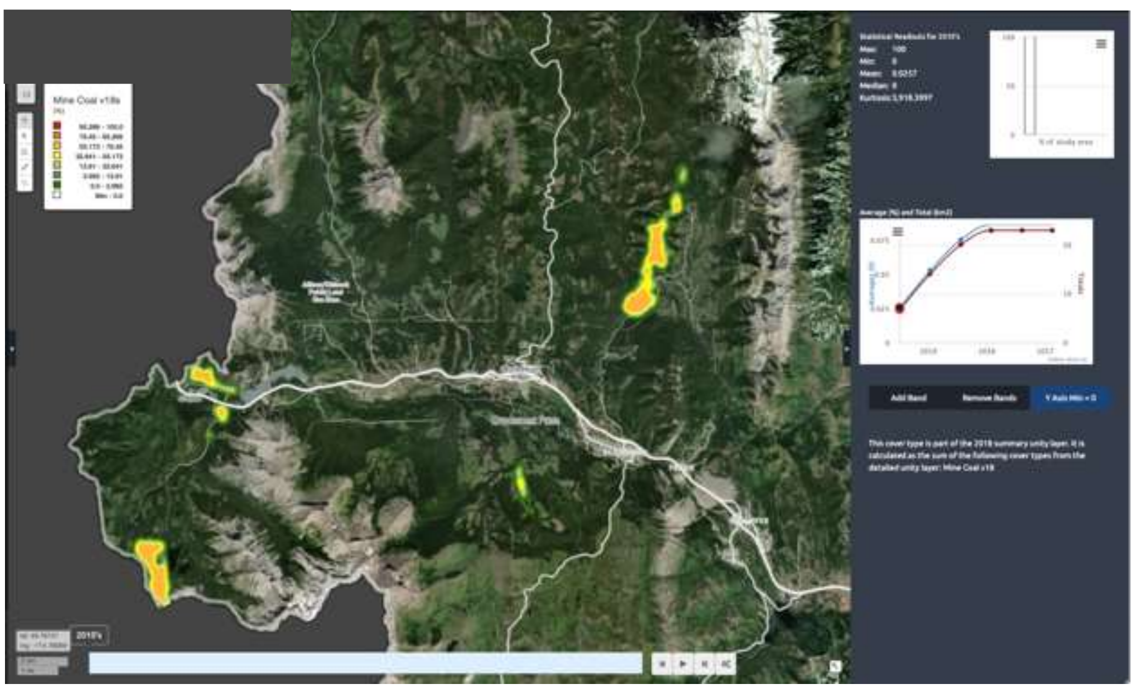


Figure 68. Extent of cumulative footprint area (2022) at start of Medium Growth simulation prior to the development of prospective coal mines in the ORW. Footprints represents current coal mines of Grassy Mtn and Tent Mountain.

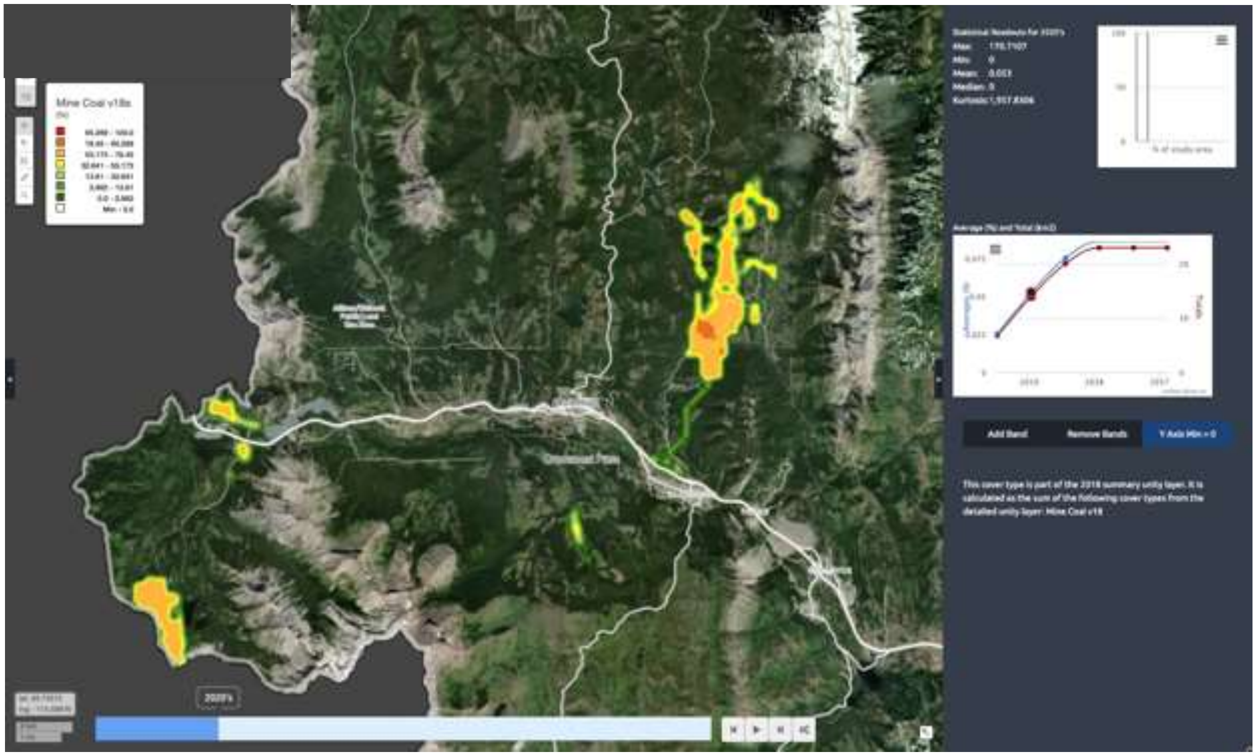


Figure 69. Extent of cumulative footprint area (Yr 2032) at end of Decade 1 of the Medium Growth simulation of the development of prospective coal mines in the ORW.

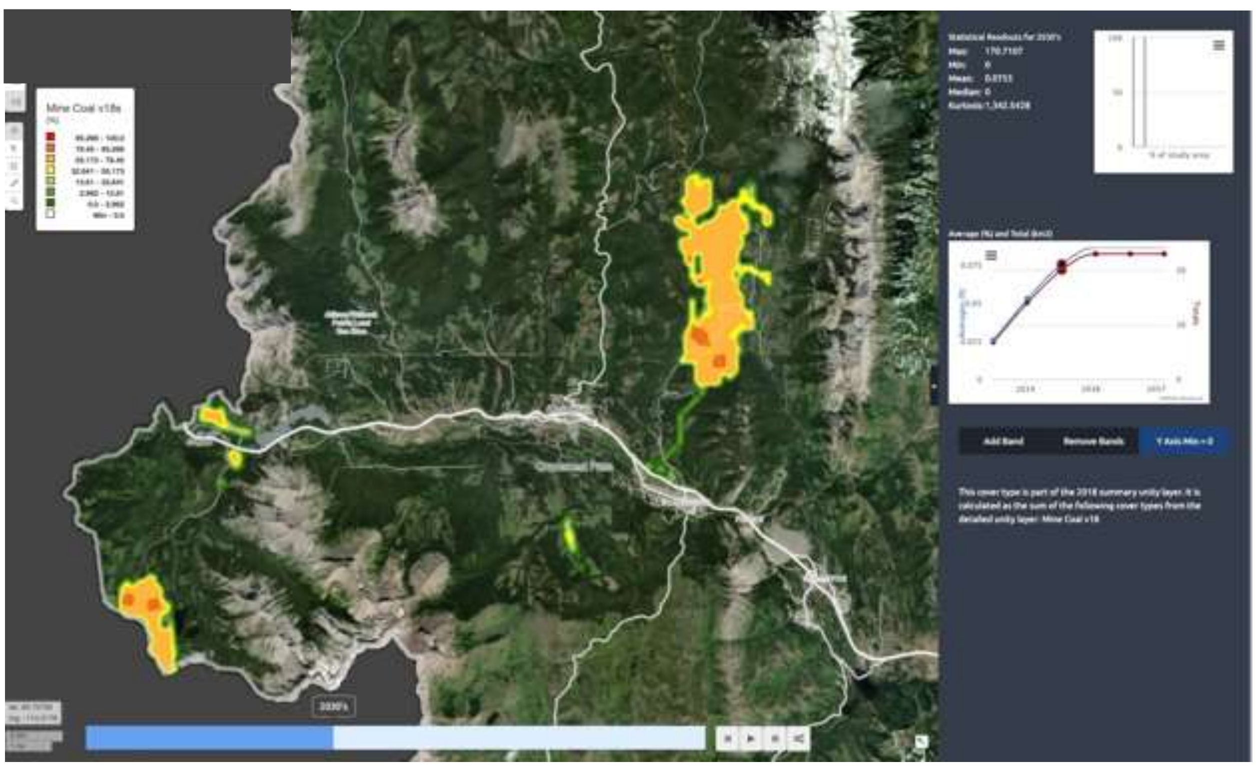


Figure 70. Extent of cumulative footprint area (Yr 2042) at end of Decade 2 of the Medium Growth simulation of the development of prospective coal mines in the ORW.

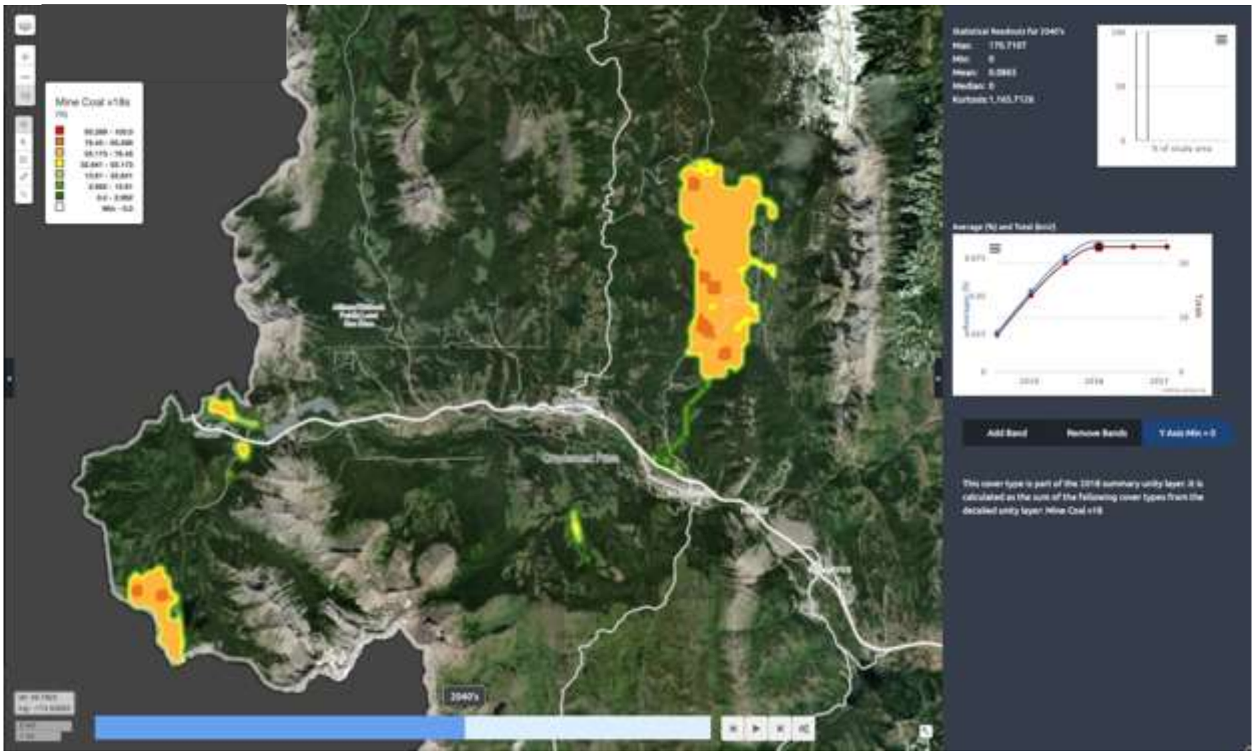


Figure 71 Extent of cumulative footprint area (Yr 2052-2072) at end of Decade 3-5 of the Medium Growth simulation of the development of prospective coal mines in the ORW. By the end of Decade 3, no further development is occurring on the mine site.

High Growth Scenario (all eight coal mines)

In the high coal development scenario, the initial 2021 coal mine footprint (from legacy mines of Grassy Mtn, Tent Mtn) of 6.84 km^2, grows to a maximum of ~93.46 km^2 by the end of 5 decades (Figure 72). The decade by decade trajectory of this development is shown in Figure 73-Figure 78.

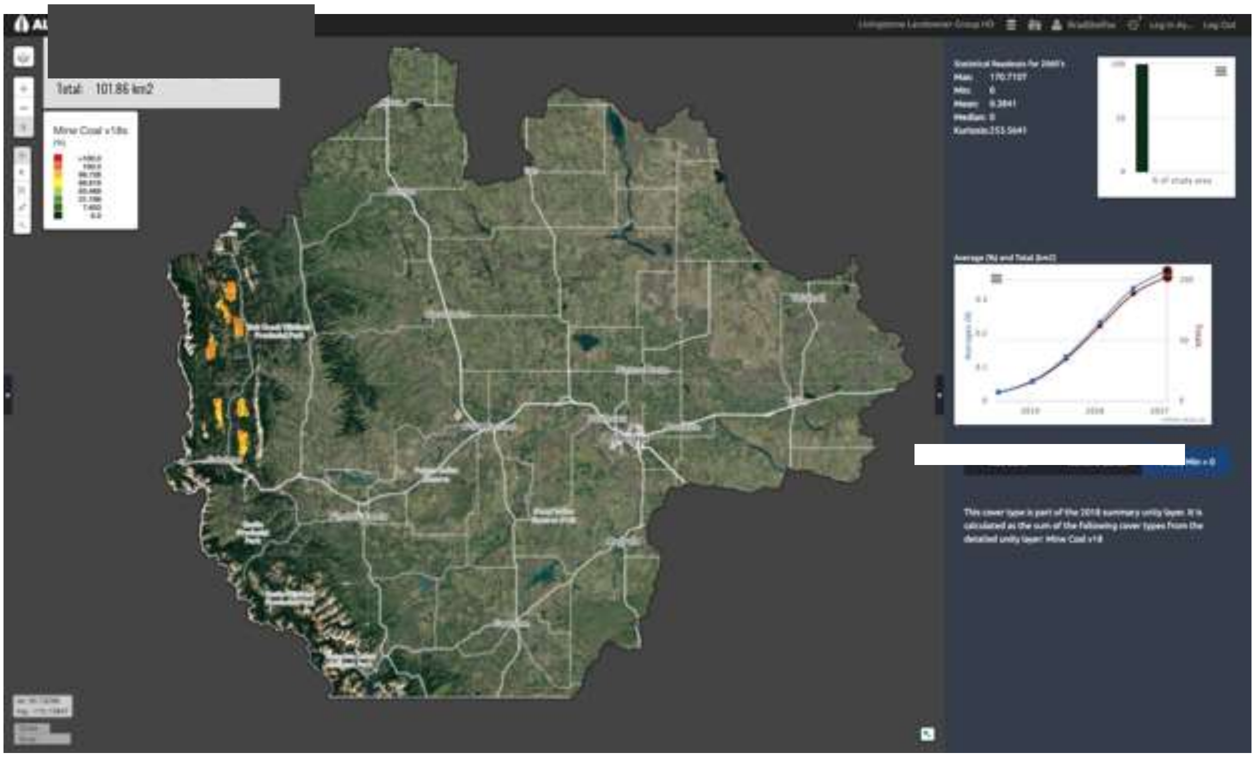


Figure 72. Simulated extent of cumulative footprint area (2022-2072) of prospective coal mines in the ORW.

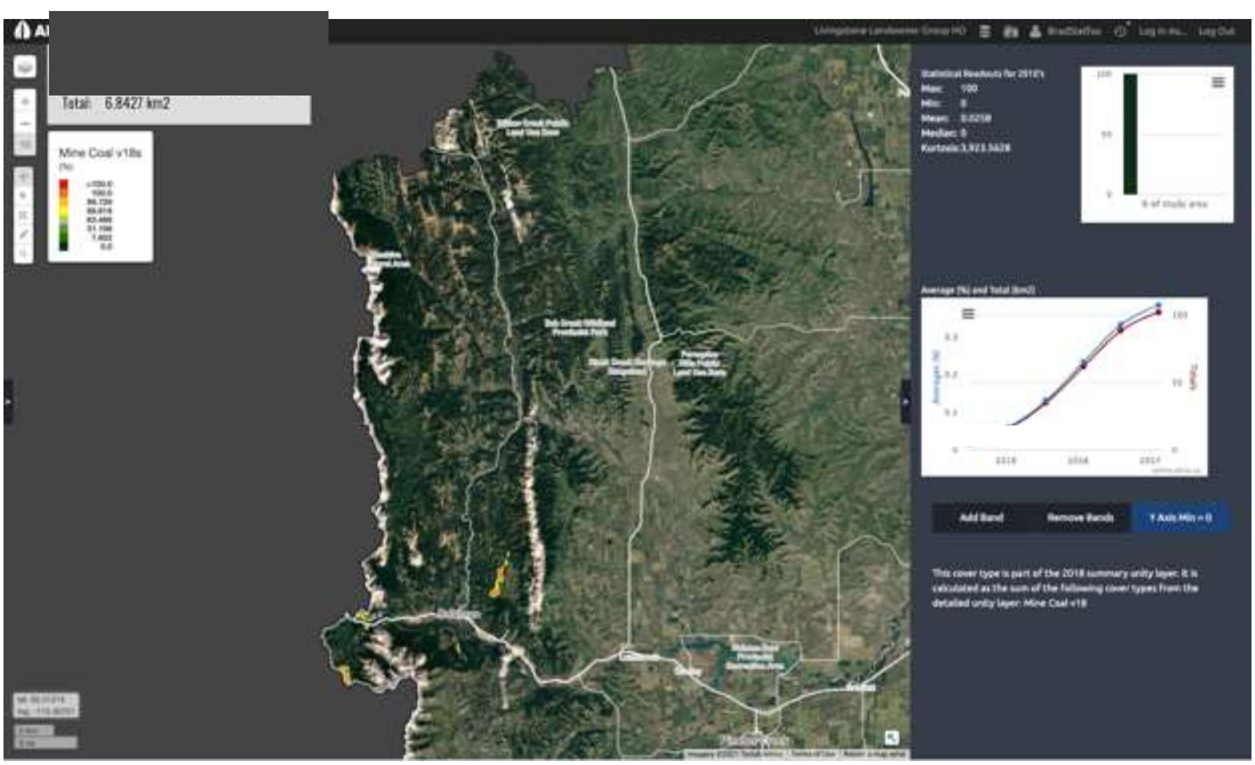


Figure 73. Extent of cumulative footprint area (2022) at start of simulation prior to the development of prospective coal mines in the ORW. Footprints represents current coal mines of Grassy Mtn and Tent Mountain.

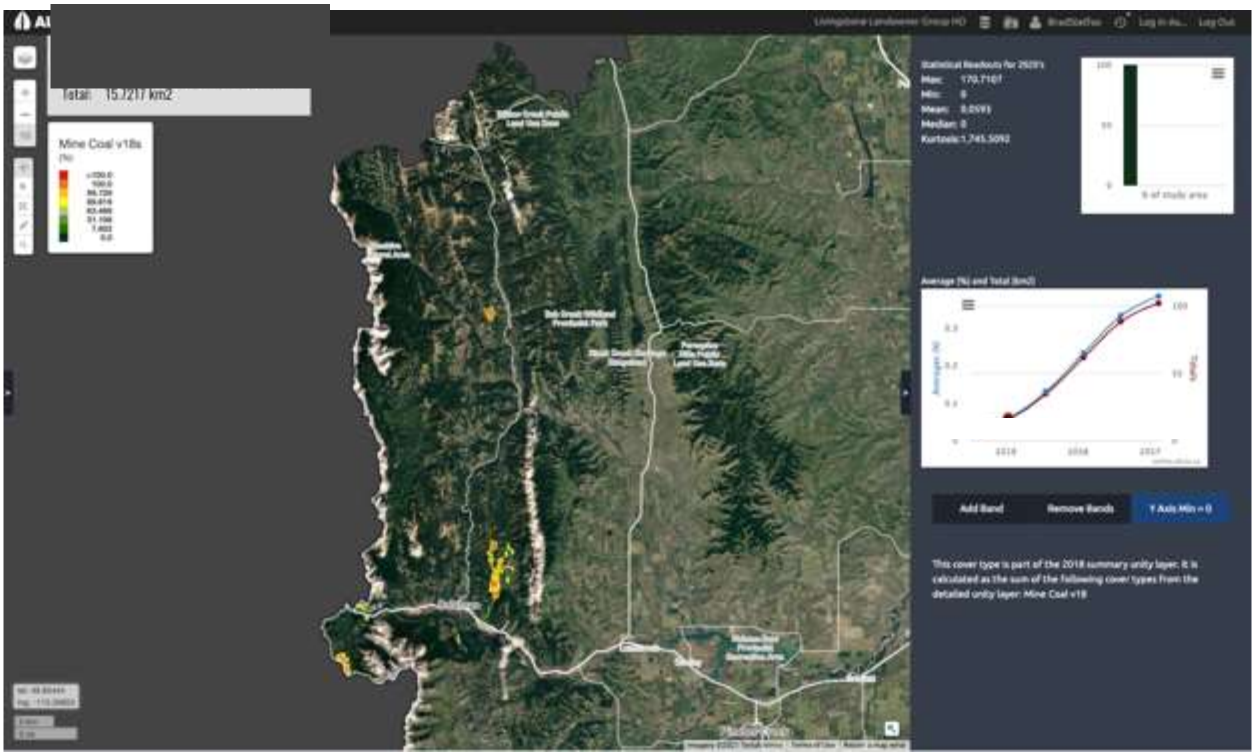


Figure 74. Extent of cumulative footprint area (Yr 2032) at end of Decade 1 of the High Growth simulation of the development of prospective coal mines in the ORW.

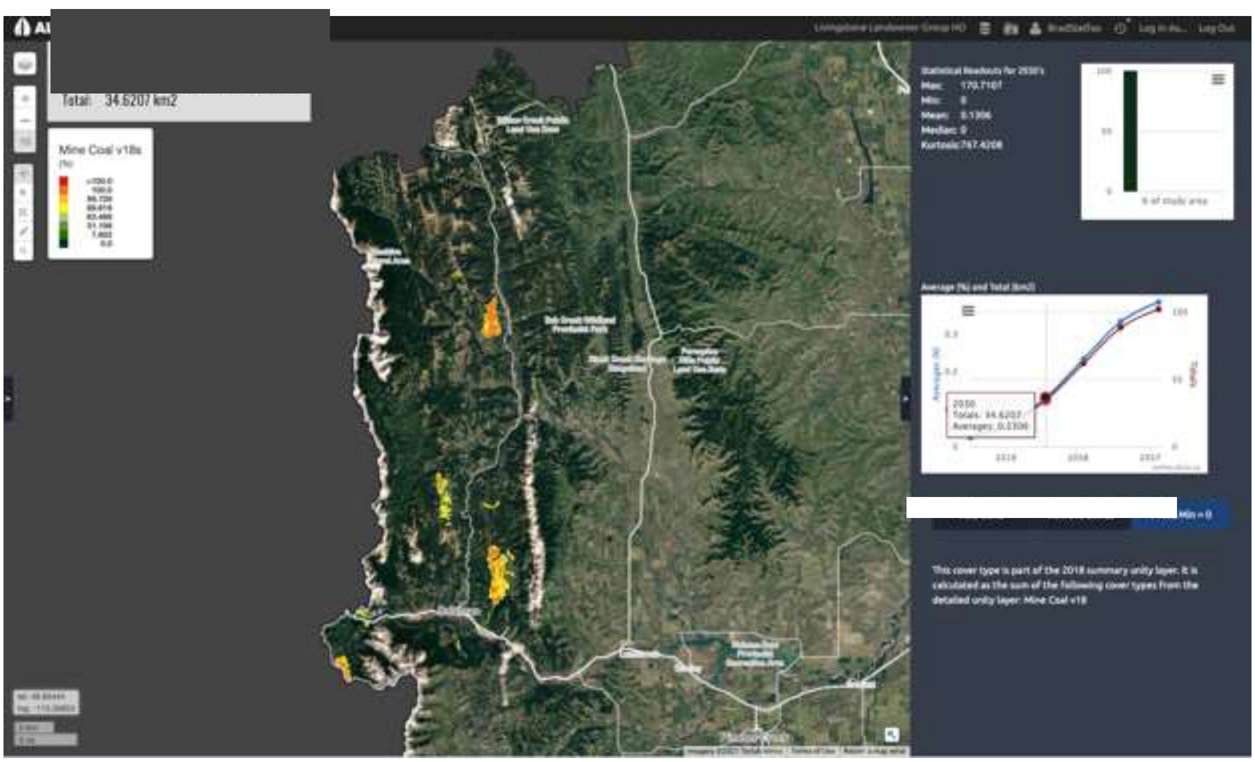


Figure 75. Extent of cumulative footprint area (Yr 2042) at end of Decade 2 of the High Growth simulation of the development of prospective coal mines in the ORW.

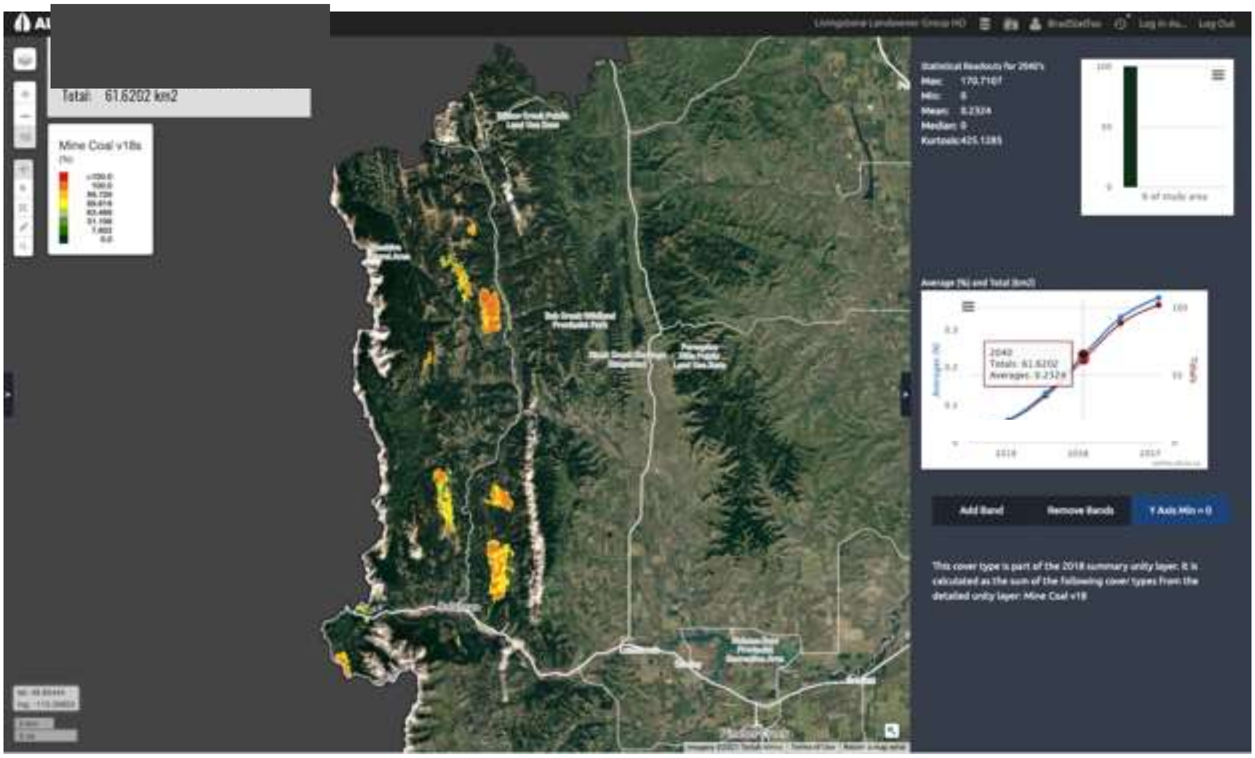


Figure 76. Extent of cumulative footprint area (Yr 2052) at end of Decade 3 of the High Growth simulation of the development of prospective coal mines in the ORW.

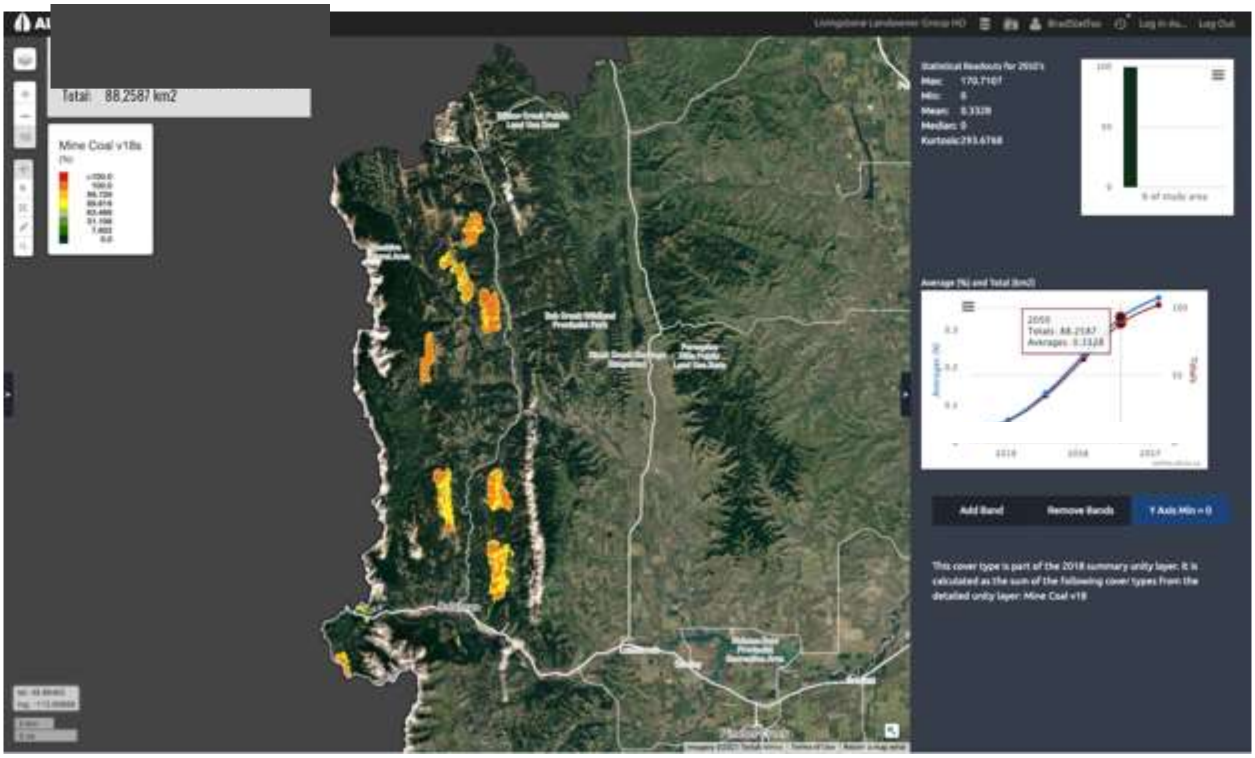


Figure 77. Extent of cumulative footprint area (Yr 2062) at end of Decade 4 of the High Growth simulation of the development of prospective coal mines in the ORW.

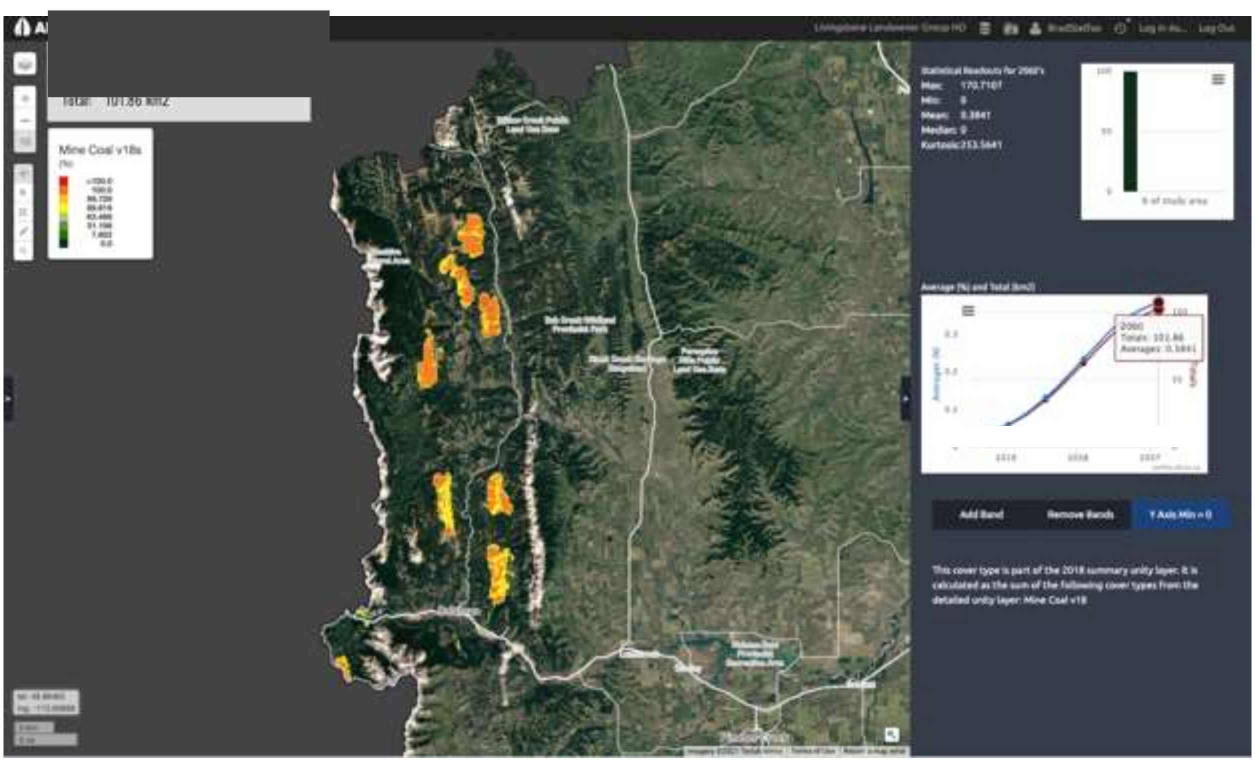
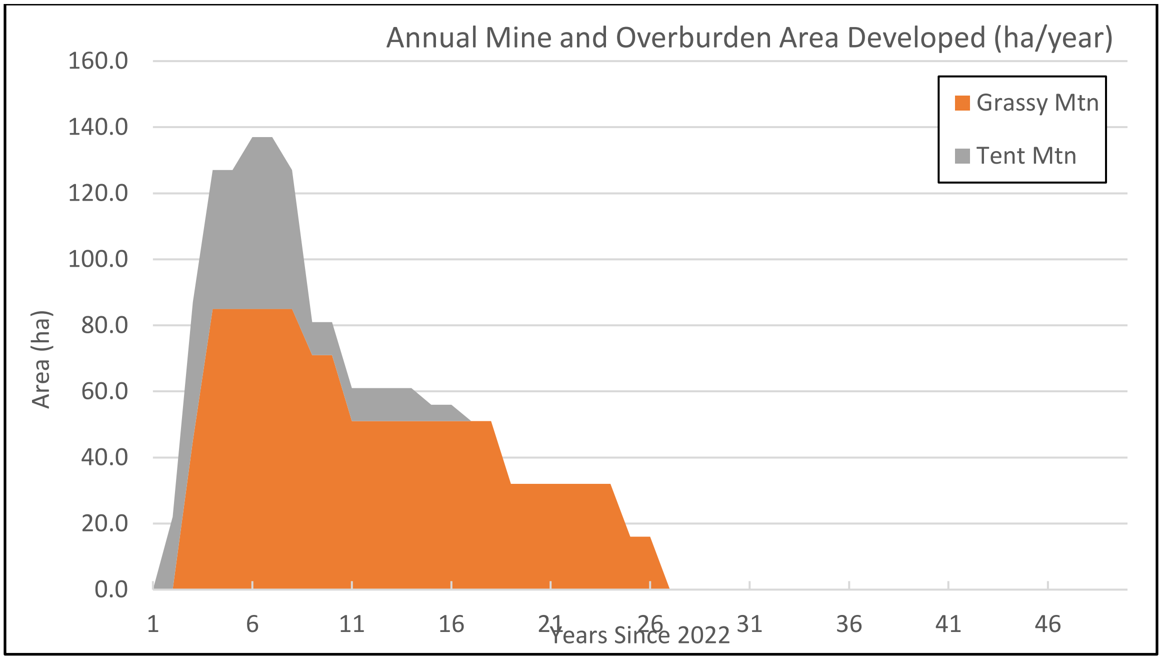


Figure 78. Extent of cumulative footprint area (Yr 2072) at end of Decade 5 of the High Growth simulation of the development of prospective coal mines in the ORW.

Disturbance Area

In the medium coal development scenario, the initial 2021 coal mine footprint (from legacy mines of Grassy Mtn, Tent Mtn) of 6.84 km^2, grows by an additional area of ~16.00 km^2 by the end of 5 decades (Figure 79). The decade by decade trajectory of this development is shown in Figure 80.

In the high coal development scenario, the disturbance area of coal mining grows to 9,411 ha by the end of 5 decades (Figure 80). The decade by decade trajectory of this development is shown in Figure 80.



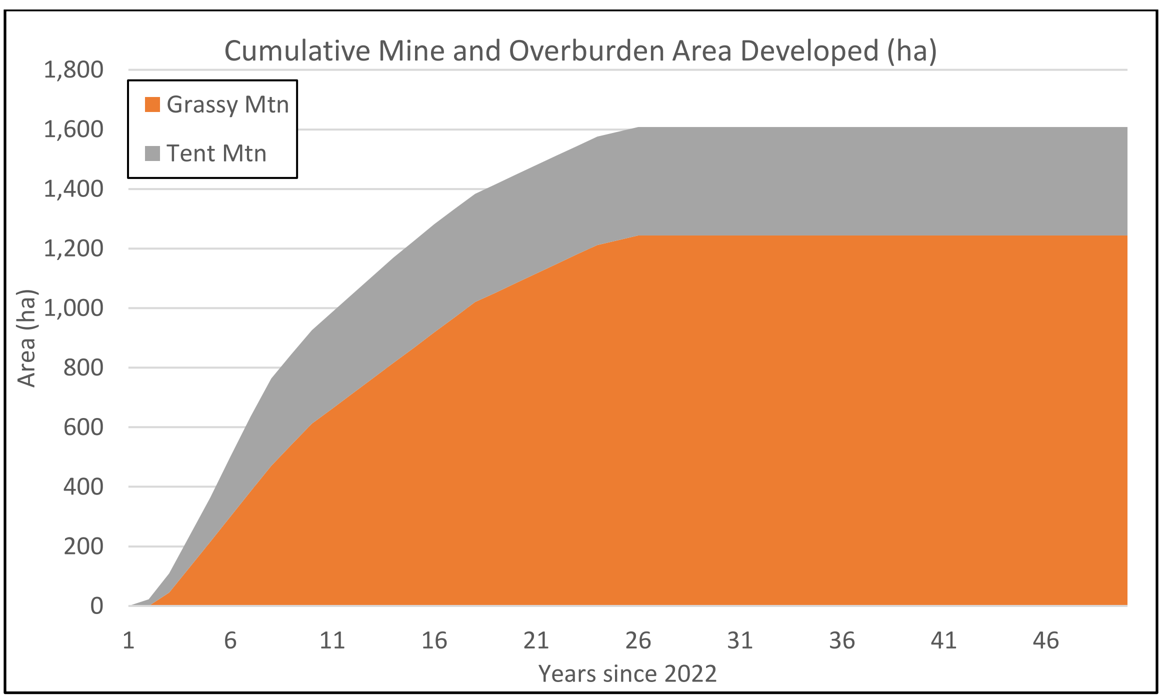
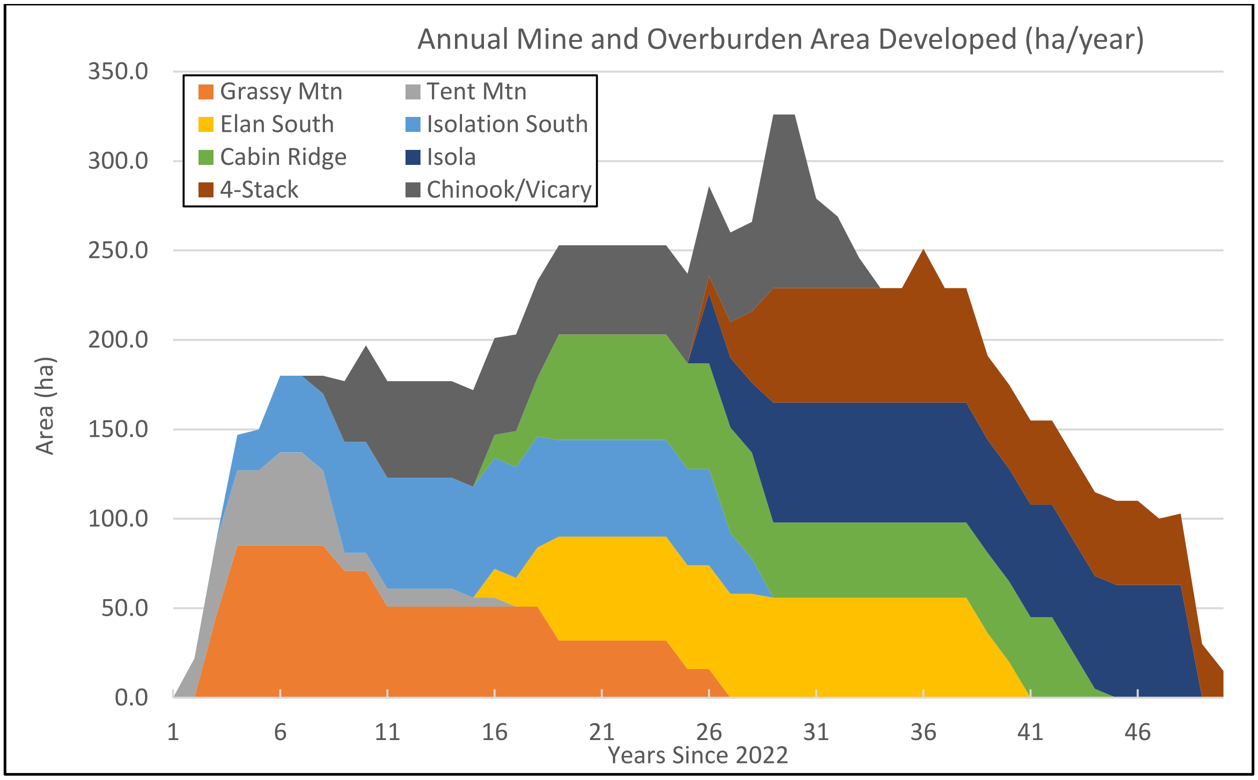


Figure 79. Annual (upper) and cumulative (lower) area of active coal mining under the Medium Growth Scenaro.



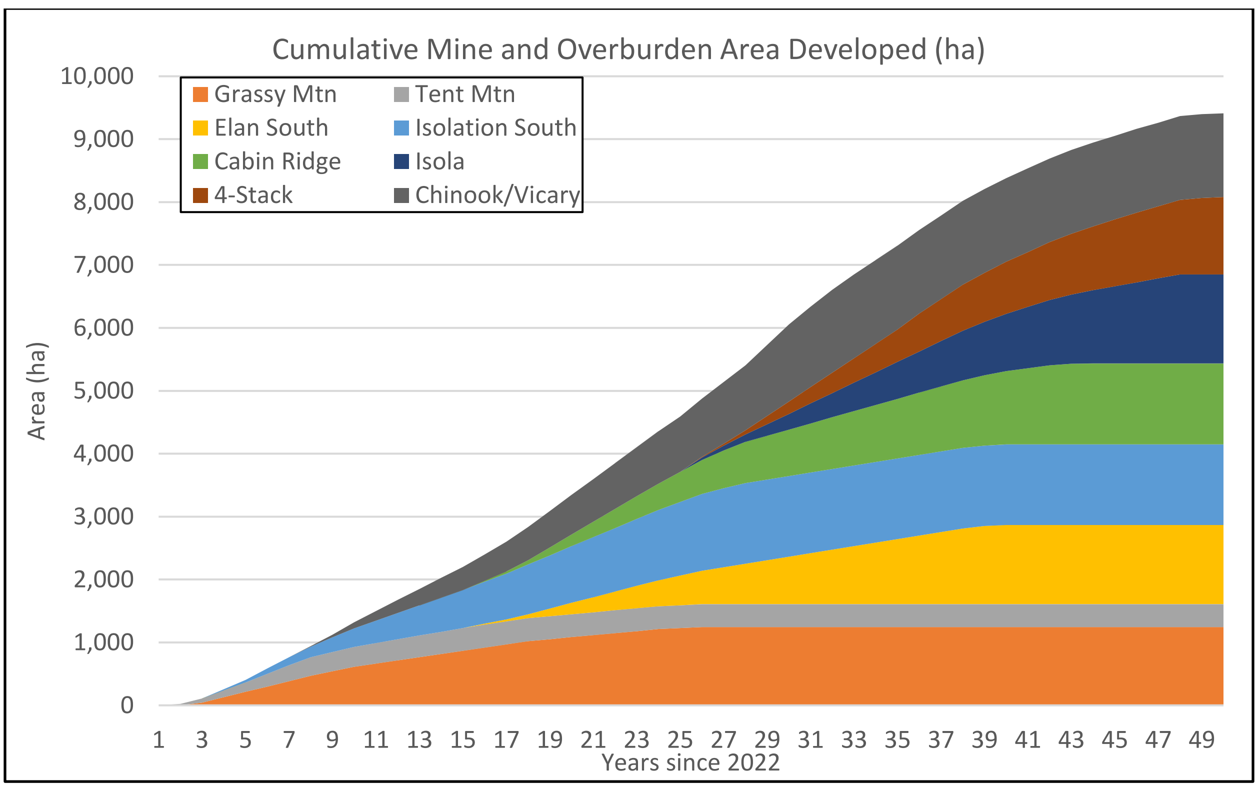
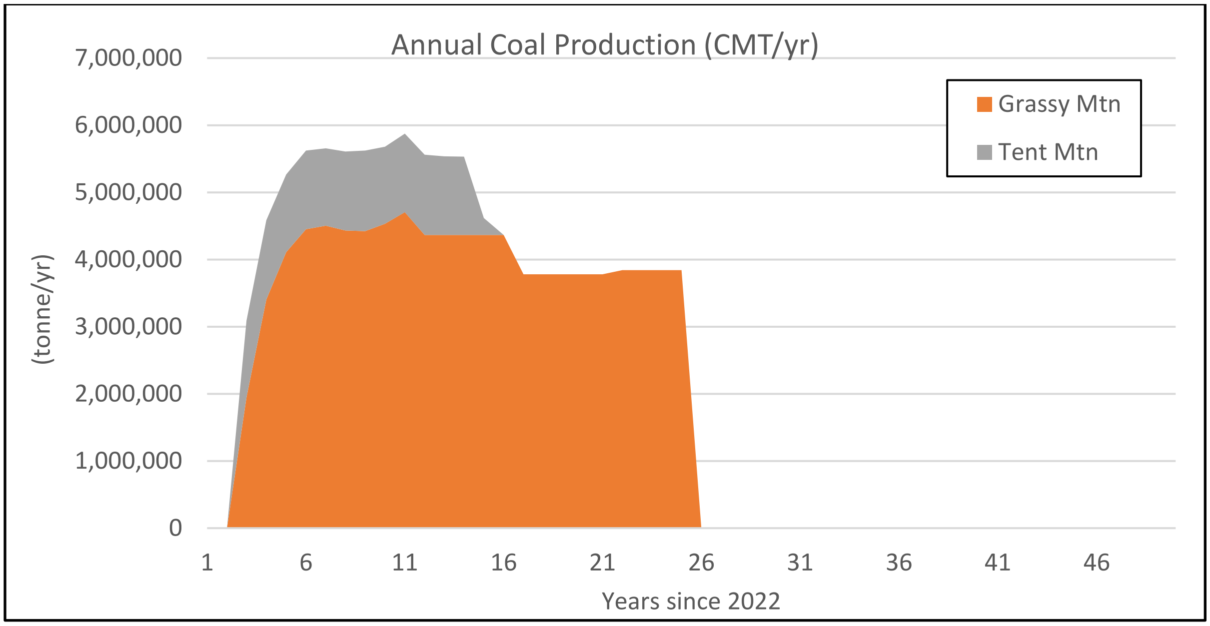


Figure 80. Annual (upper) and cumulative area (lower) of coal mining under the High Growth Scenaro.

Coal Production

In the medium coal development scenario, coal production (CMT) rapidly grows to a maximum of ~5.84 M tonne/year (~Year 10-12) with annual productions varying between 3.8 and 5.5 M tonne throughout the 20-25 year production lifespan (Figure 81). Cumulative coal production is ~107 M tonne (Figure 81).

In the high coal development scenario, coal production grows rapidly during the first 25 decades and peaks at ~23.9 M tonne/year (~Year 20-25). Cumulative coal production is ~693.7 M tonne (Figure 82).



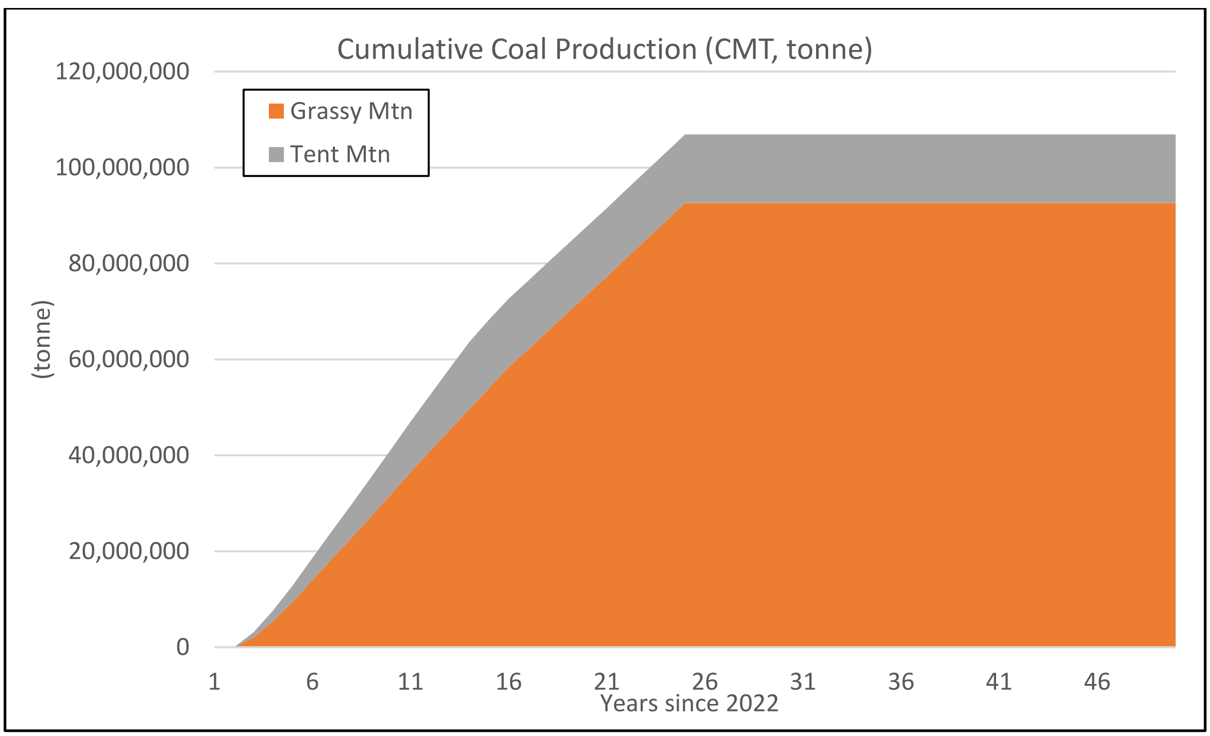
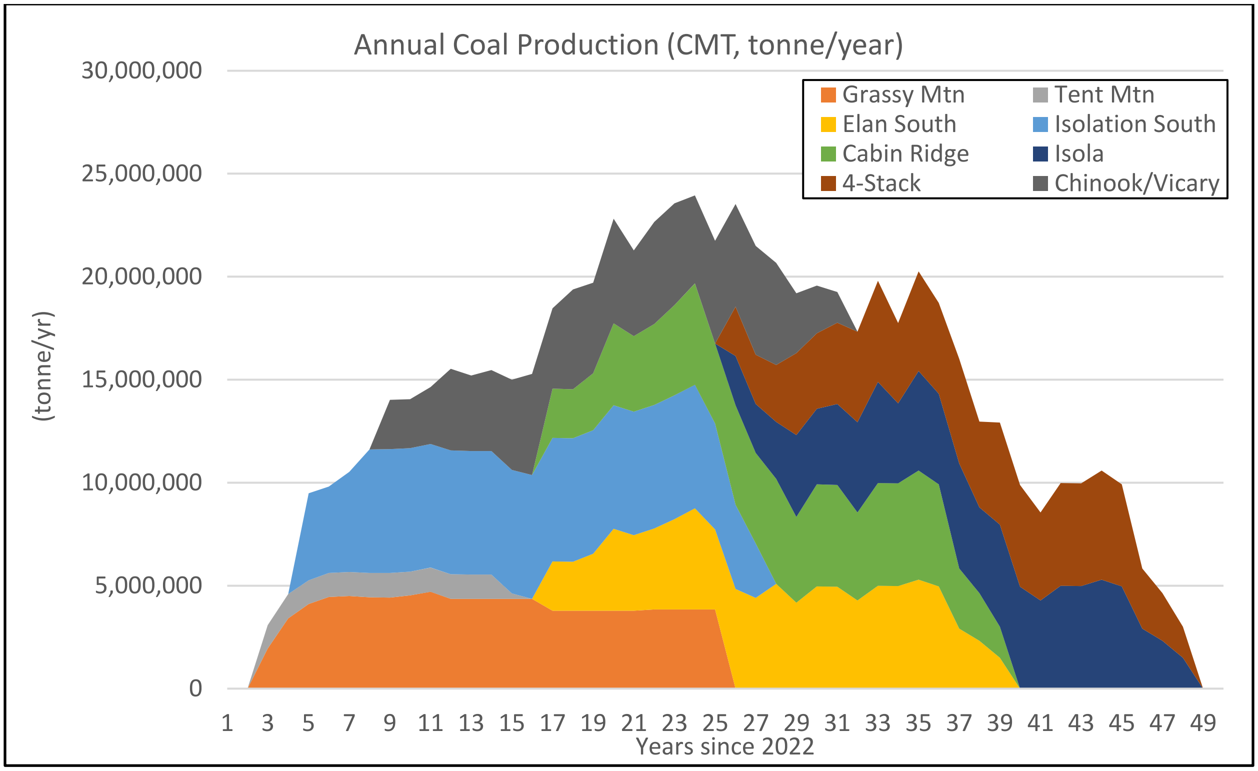


Figure 81. Annual (upper) and cumulative (lower) production (tonne) of clean coal under the Medium Growth Scenario.



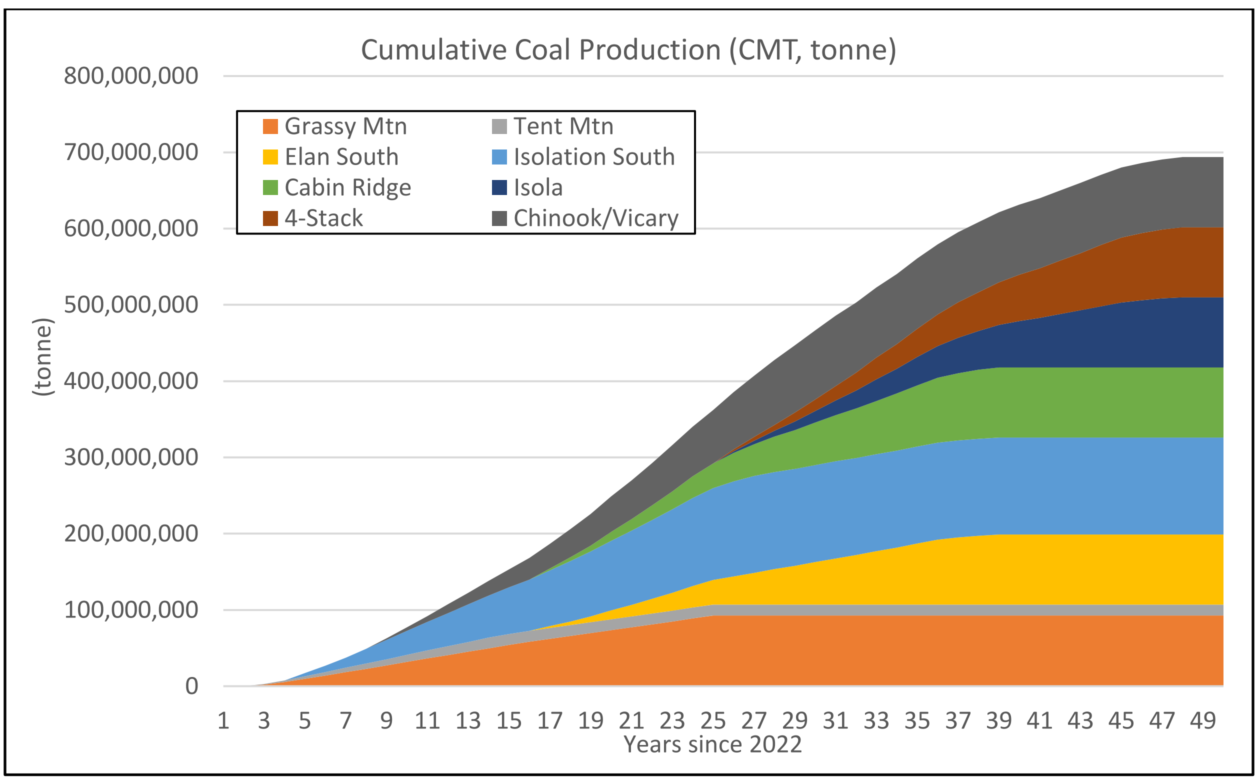
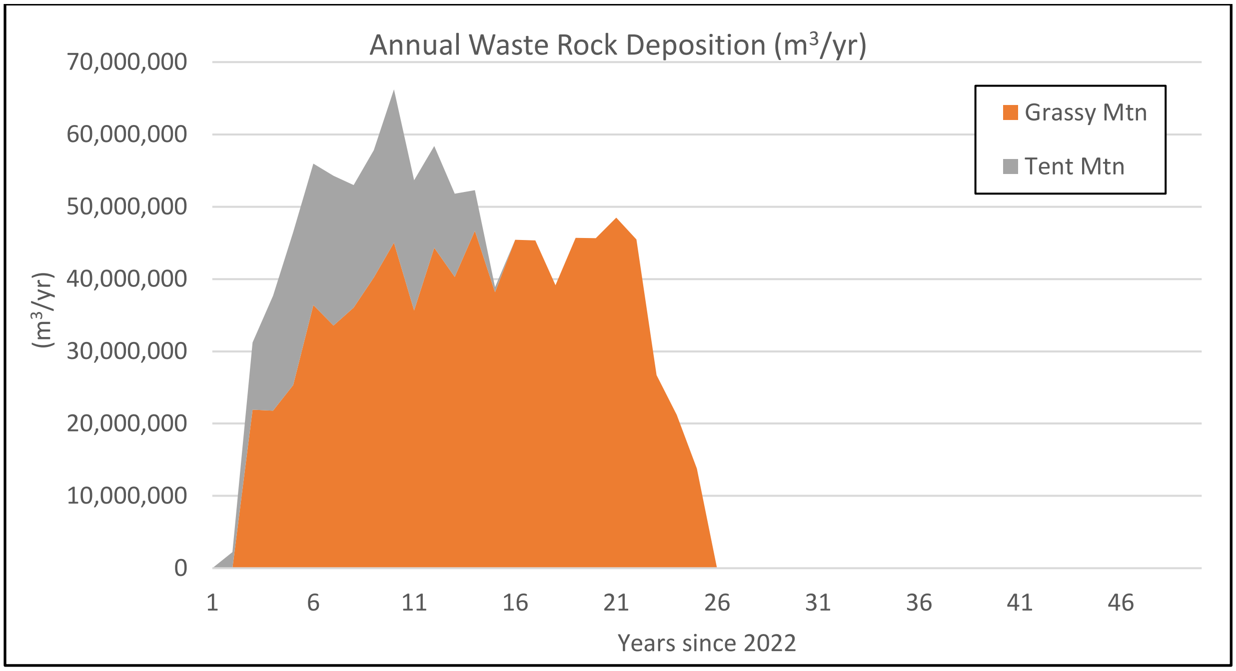


Figure 82. Annual (upper) and cumulative production (tonne) of clean coal under the High Growth Scenario.

Waste Rock Production

In the medium coal development scenario, waste rock displacement grows rapidly to a maximum of ~65 M m^3/year (~Year 10-12) with annual productions varying between 40 and 55 M m^3 throughout the 20-25 year production lifespan (Figure 83). Cumulative waste rock production and displacement is ~1.1 B m^3 (Figure 83).

In the high coal development scenario, waste rock displacement grows rapidly to a maximum of ~200 M m^3/year (~Year 10-12) with annual productions typically varying between 80 and 120 M m^3 throughout the 50 year production lifespan (Figure 84). Cumulative waste rock production and displacement is ~6 B m^3 (Figure 84).



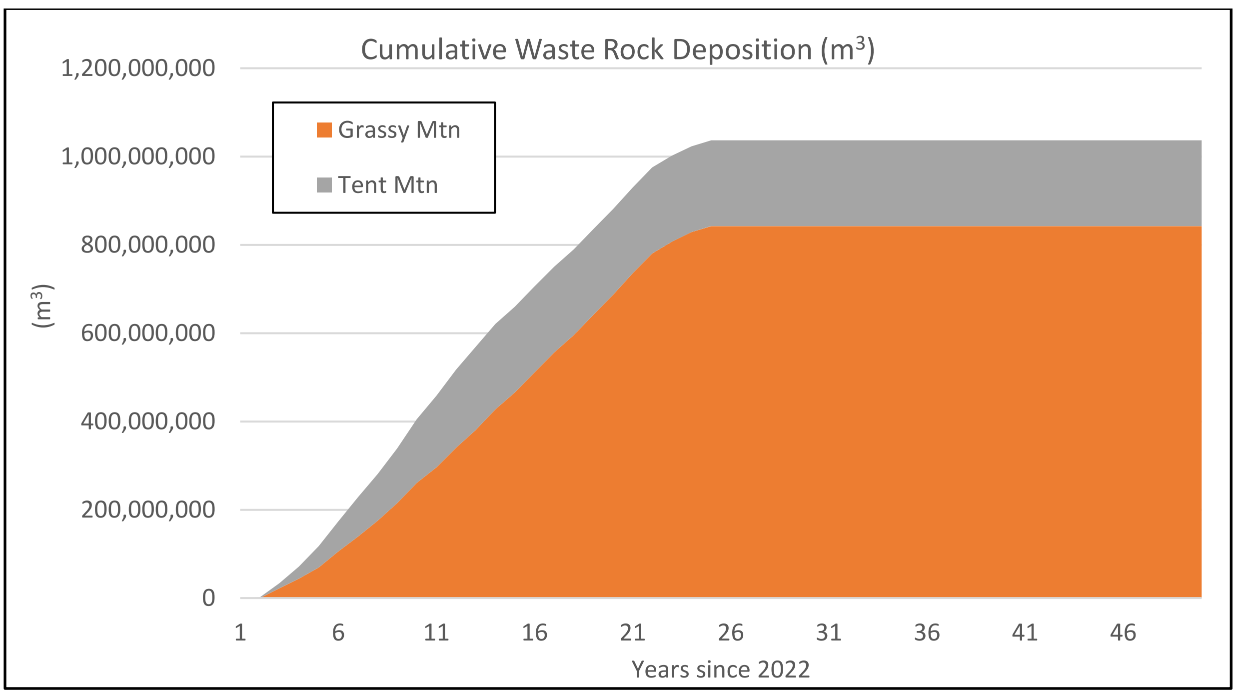
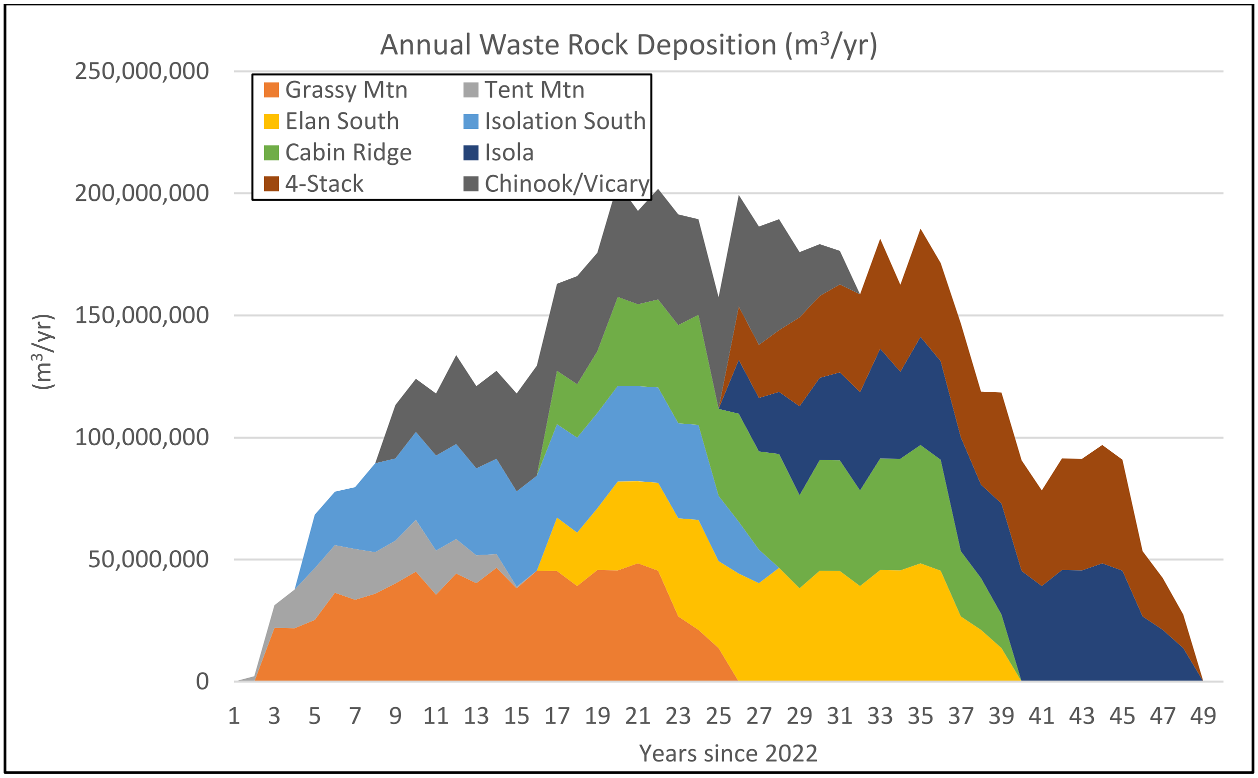


Figure 83. Annual (upper) and cumulative (lower) production (tonne) of waste rock under the Medium Growth Scenario.



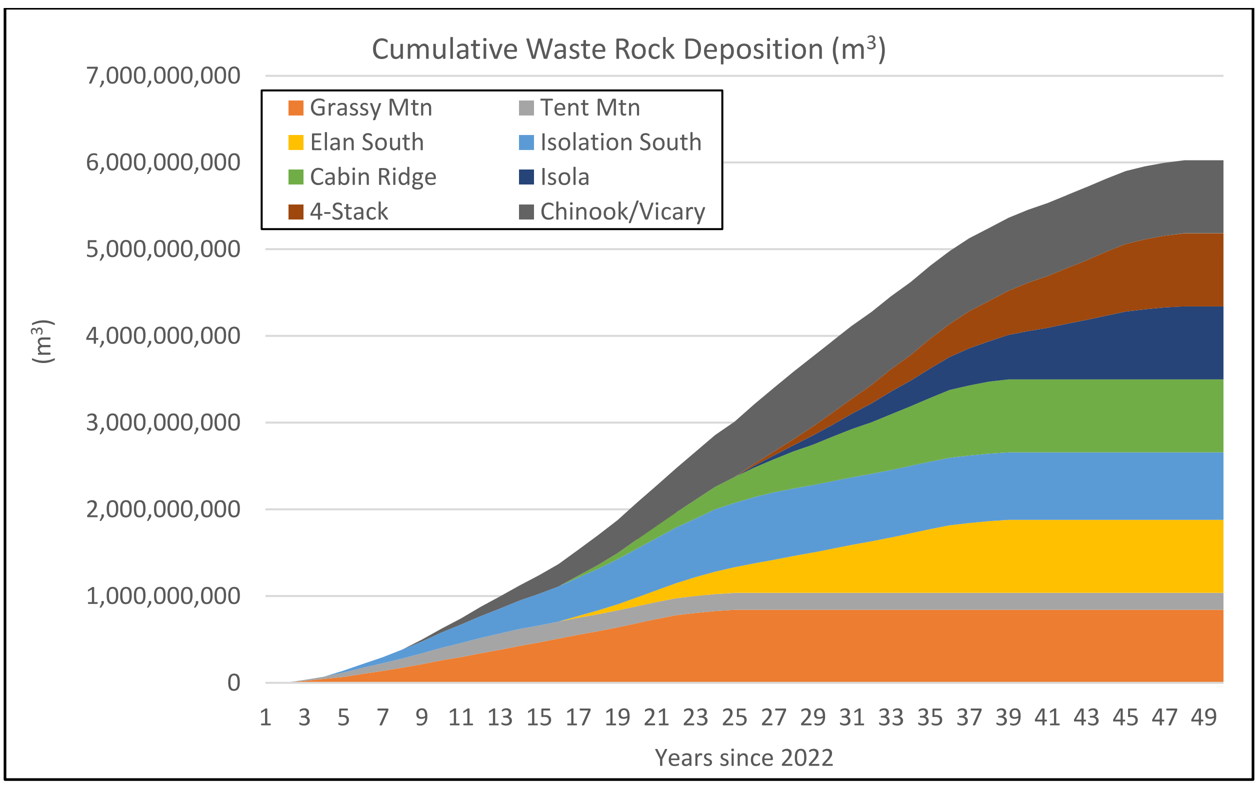


Figure 84. Annual (upper) and cumulative (lower) production (tonne) of waste rock under the High Growth Scenario.

Visualizing the Volume of Earth Disturbed by Coal Mining

The volume of coal produced in the ORW headwaters over 5 decades is estimated at 130 M tonne and 770 M tonne under the medium and high growth scenarios, respectively. The mining of coal requires the removal of overburden material and the subsequent displacement of this material as waste rock. Waste rock is of lower density (tonne/m^3) than overburden because it has been blasted by explosives prior to its displacement. The stripping ratio (m^3 of overburden per tonne of coal) varies between the mine sites but averages about 10:1. The total amount of material (coal plus overburden) displaced by all coal mining activities is estimated at 1.3 B m^3 (1.3 km^3; cubic kilometers), and 6.7 B m^3 (6.7 km^3; cubic kilometers) during the medium and high growth scenarios, respectively. The overall topography of the mined landscape will experience a re-structuring in the order of 6-7 cubic kilometers. In general, higher elevation areas will be reduced in elevation, and lower elevation areas will increase in elevation.

As a potential reference that resonates better with stakeholders, we calculated the volume of the iconic Crowsnest Mountain (Figure 85), which is perhaps the best known topographic feature in the ORW. The volume of waste rock and coal that will be displaced or moved is estimated at 1.0 and 5.4 "Crowsnest Mtn units" for the medium and high coal mine growth scenarios, respectively.

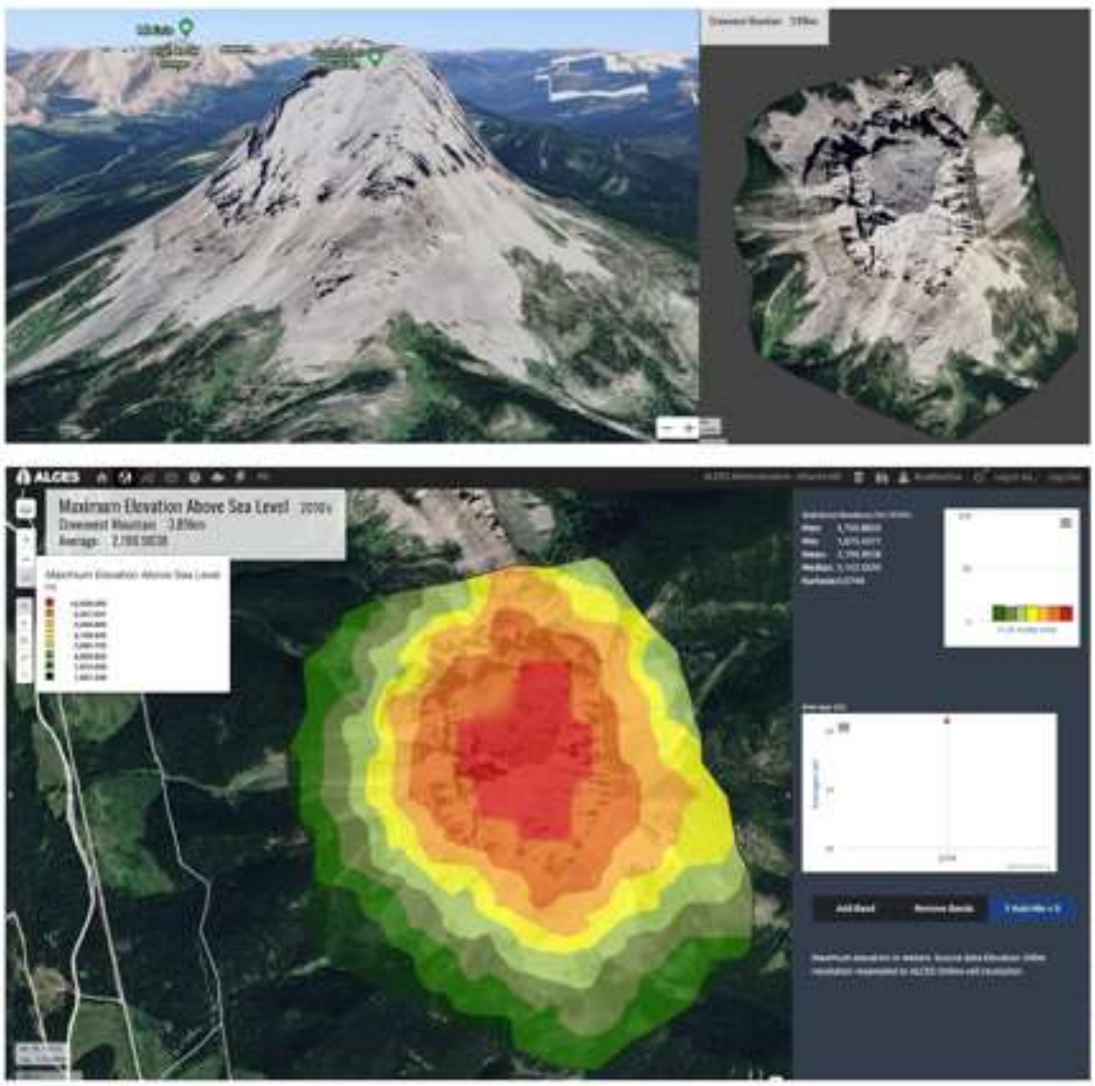
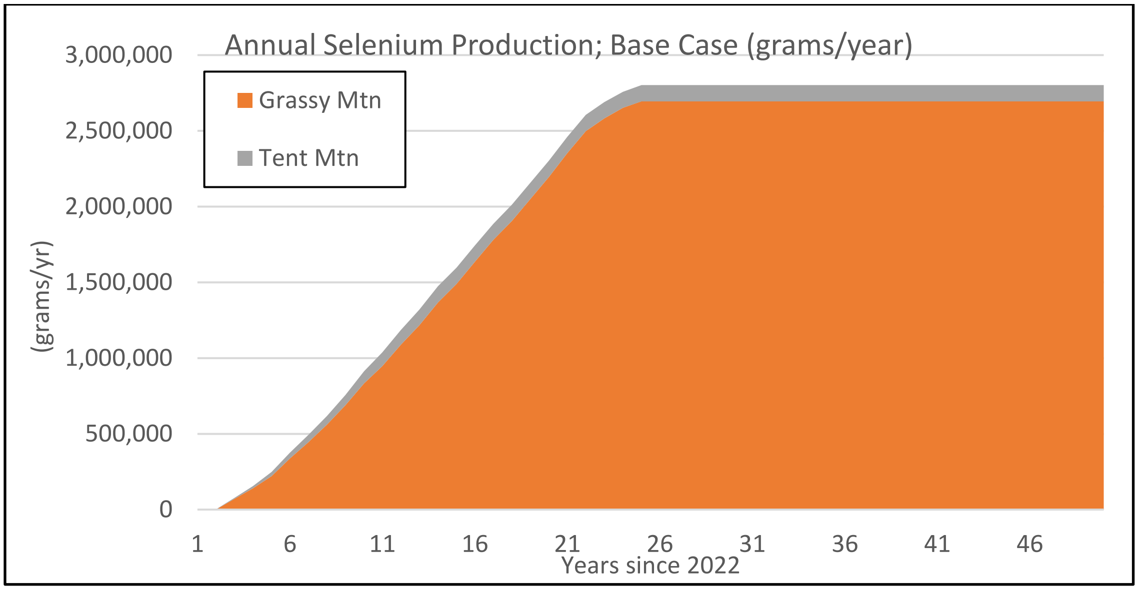


Figure 85. Crowsnest Mountain as a reference point for visualizing the volume of displaced coal and overburden rock.

Selenium Loading

In the medium coal development scenario, annual selenium production (load) grows in a linear manner from years 1-22 and levels off at ~2.75 tonne/year (=2,750 kg/yr or 2.75 M grams/year) throughout the remaining 50 year simulation (Figure 86). Cumulative selenium production during the 5 decade simulation exceeds 100 tonne of selenium (Figure 86).

In the high coal development scenario, annual selenium production (load) grows consistently throughout the 5 decade simulation, and achieved annual production rates exceeding 10 tonne/year by Year 50. Average annual rates are ~5.6 tonne/year throughout the 50 year simulation (Figure 87). Cumulative selenium production during the 5 decade simulation exceeds ~280 tonne of selenium (Figure 87).



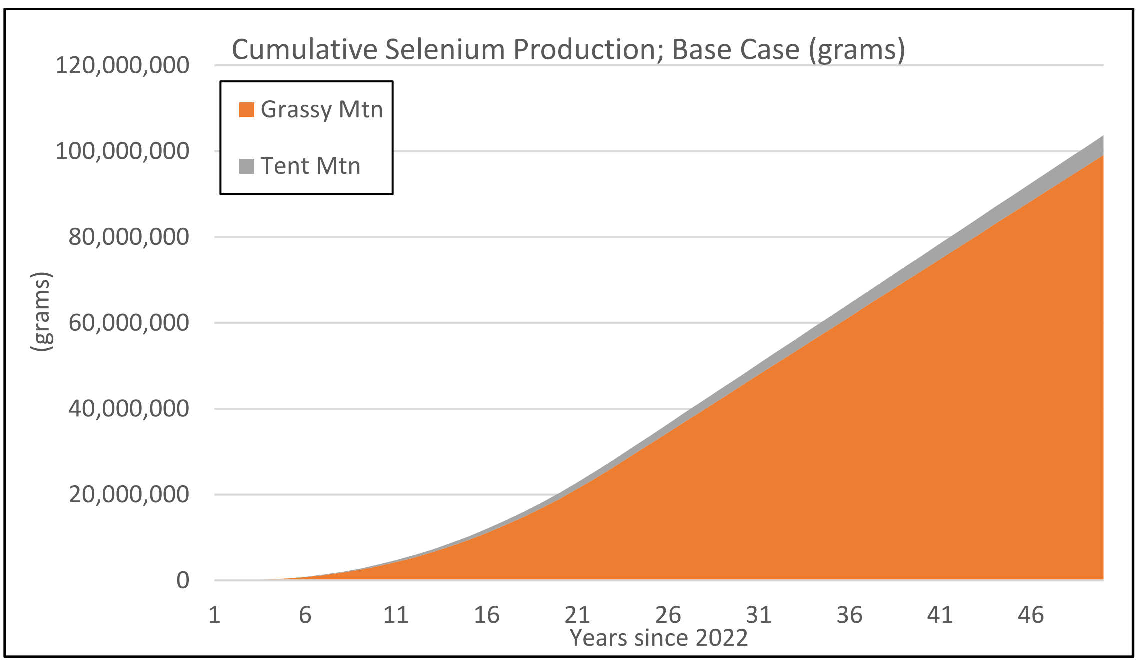
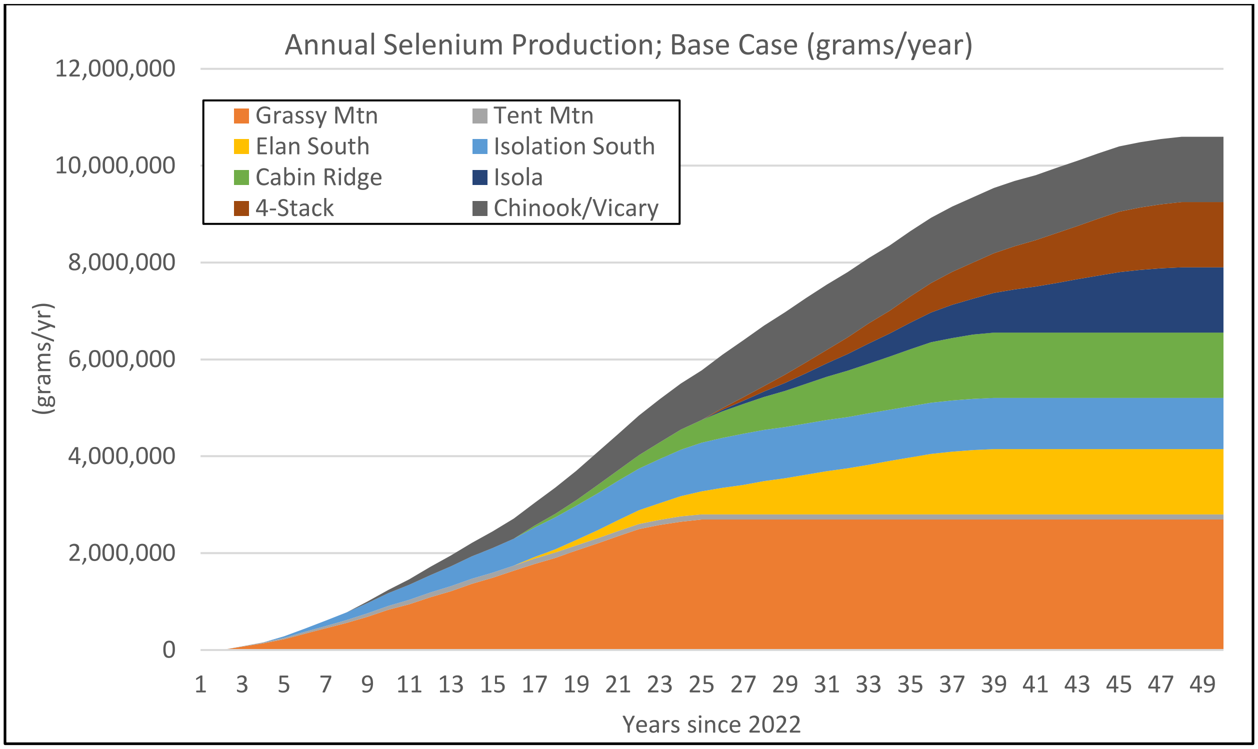


Figure 86. Annual (upper) and cumulative(lower) production (grams) of selenium (Se) under the Medium Growth Scenario.



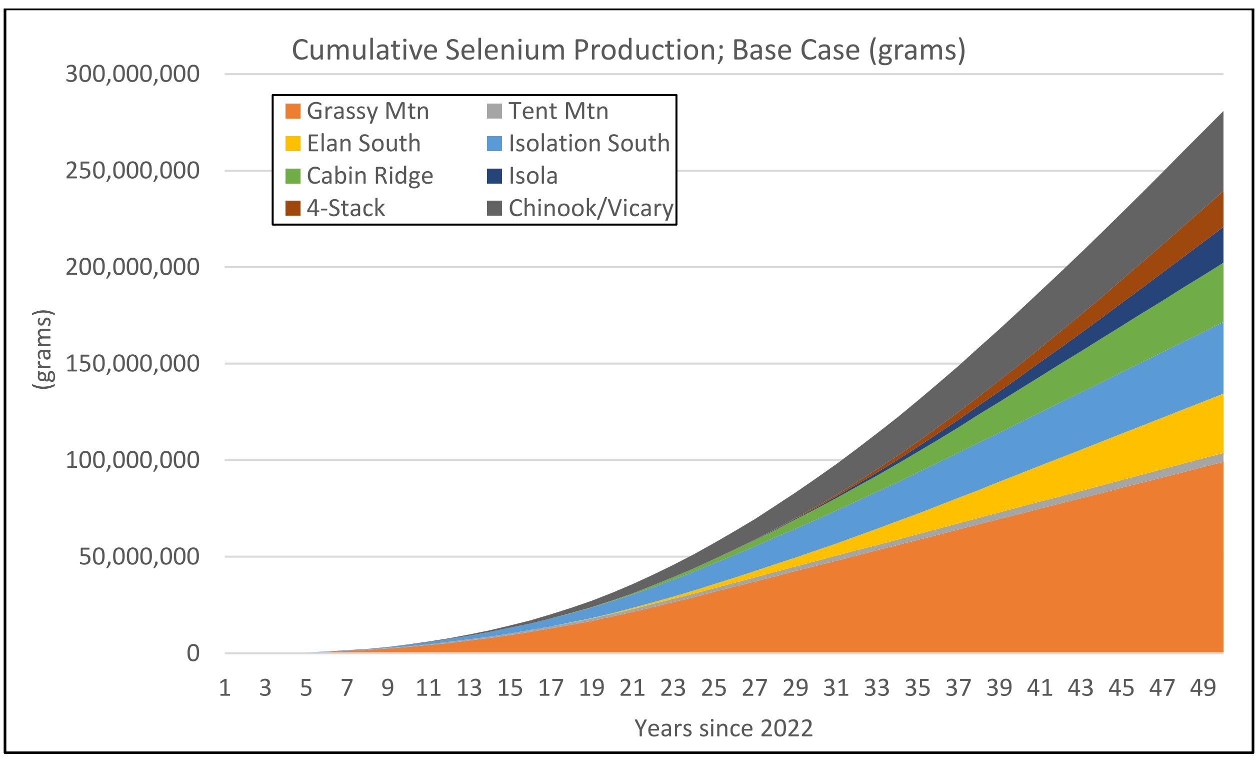


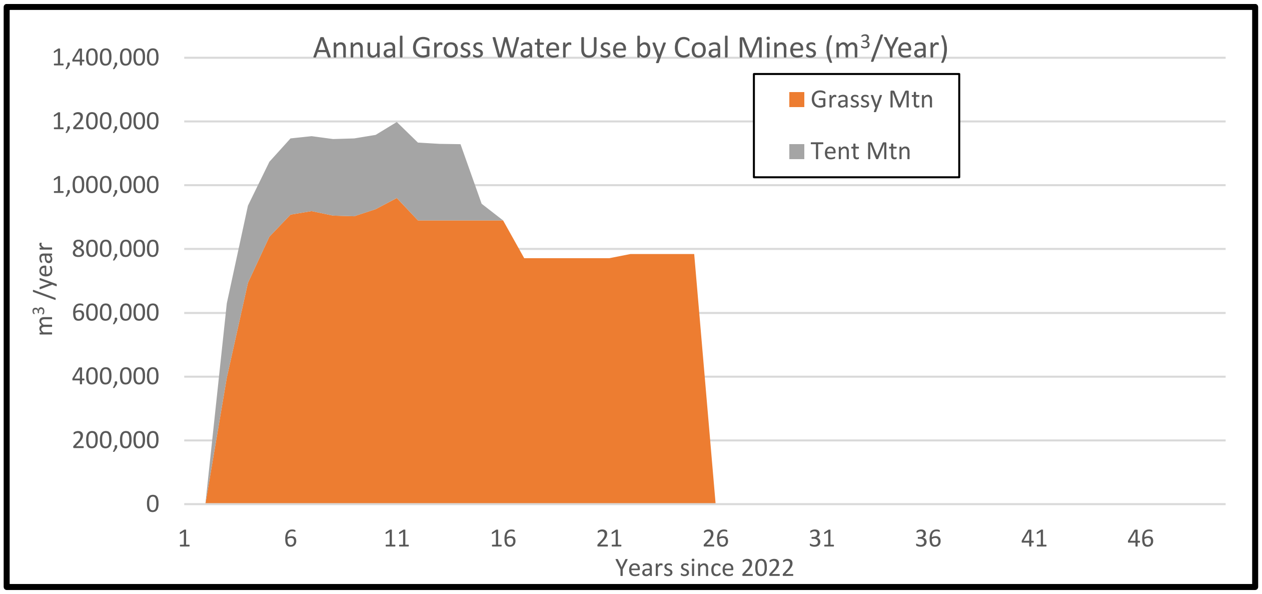
Figure 87. Annual (upper) and cumulative (lower) loading (grams) of selenium (Se) under the High Growth Scenario.

Water Use from Coal Mines

In the medium coal development scenario, gross water use grows rapidly to a maximum of ~1.2 M m^3/year (~Year 10-12) with annual use varying between 0.8 and 1.1 M m^3 throughout the 20-25 year production lifespan (Figure 88). Cumulative gross water use throughout the 5 decade simulation is ~22 M m^3 (Figure 88).

In the high coal development scenario, water use grows rapidly between Year 1 and 25 to a maximum of ~4.9 M m^3/year, and then declines during decades 2-5 as coal production gradually declines (Figure 90). Cumulative water use throughout the 5 decade simulation is ~140 M m^3 (Figure 90).

In both medium and high coal growth scenarios, consumptive water use is 33% of gross water use values (Figure 89, Figure 91).



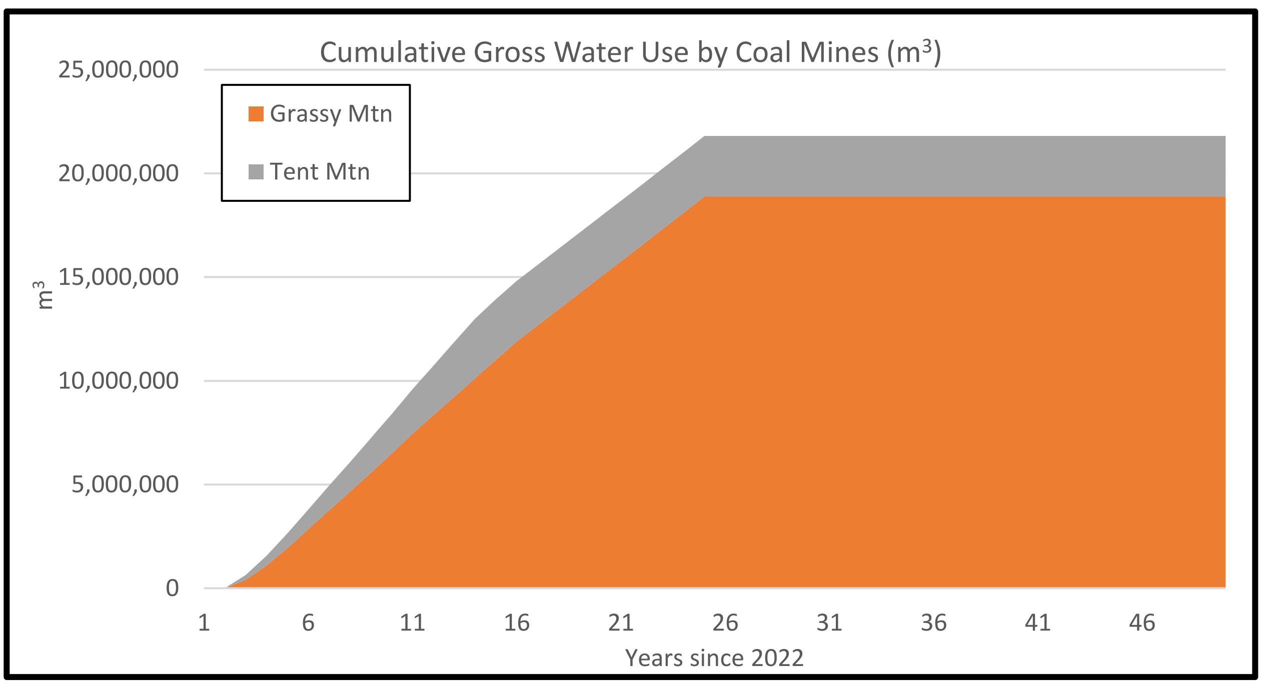
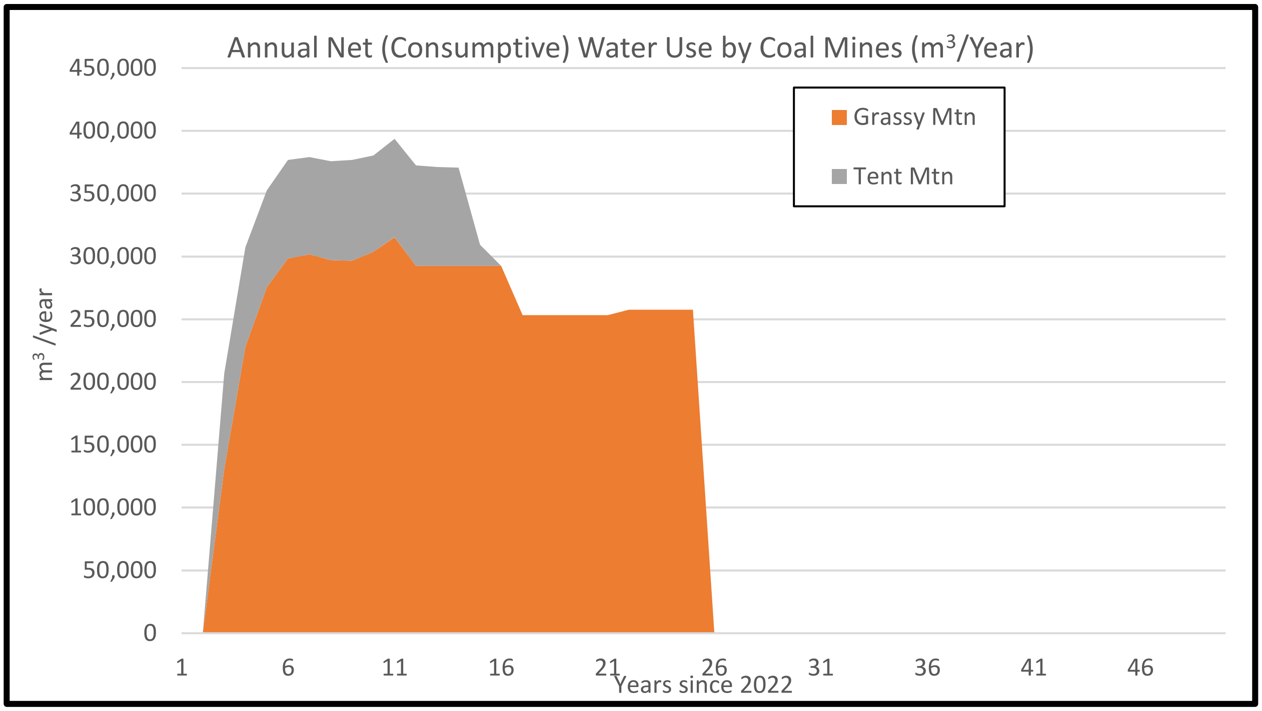


Figure 88. Annual (upper) and cumulative (lower) gross water use by coal mines under the Medium Growth Scenario.



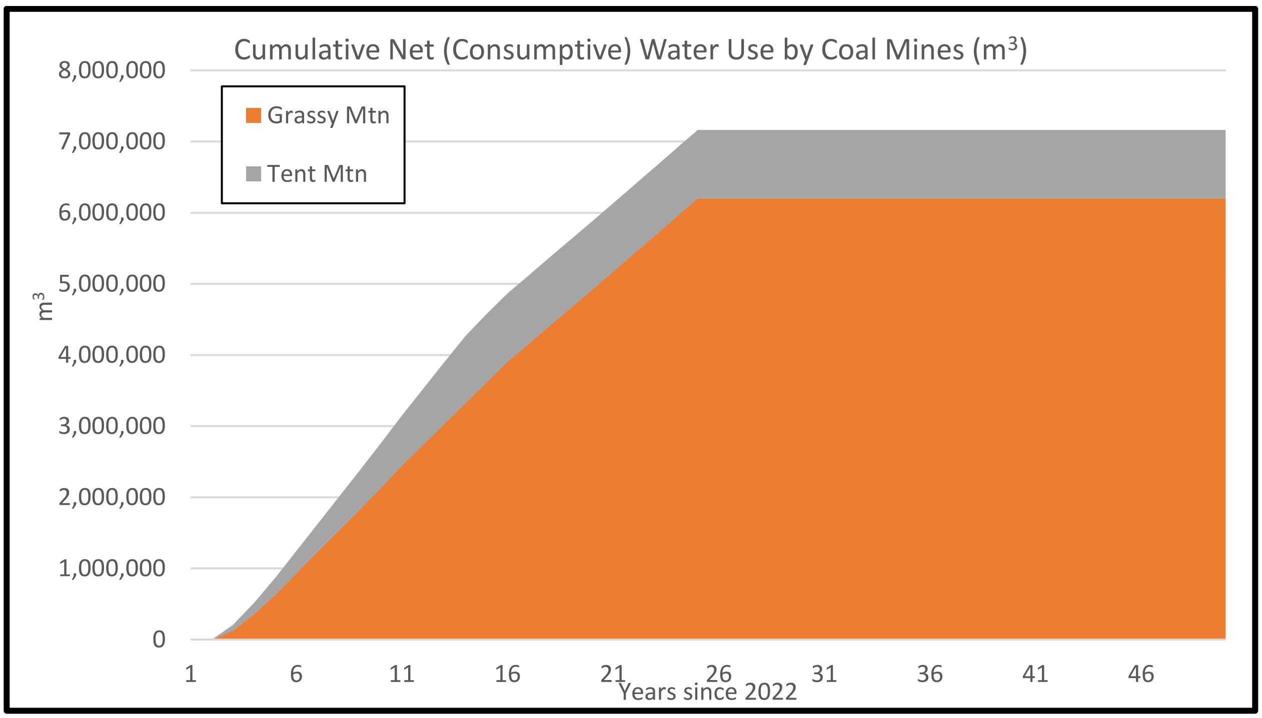


Figure 89. Annual (upper) and cumulative (lower) net (consumptive) water use by coal mines under the Medium Growth Scenario.

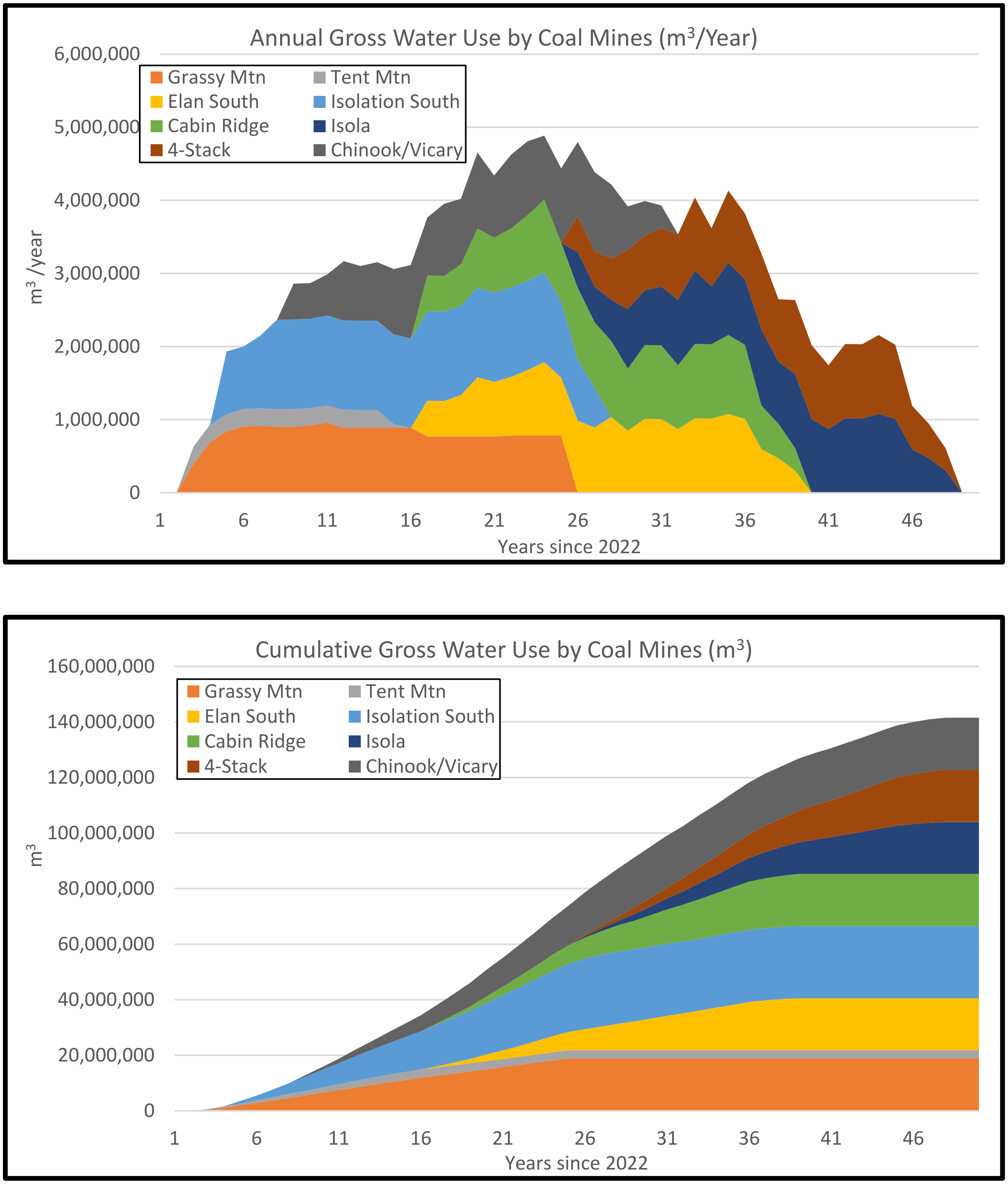


Figure 90. Annual (upper) and cumulative (lower) gross water use by coal mines under the High Growth Scenario.

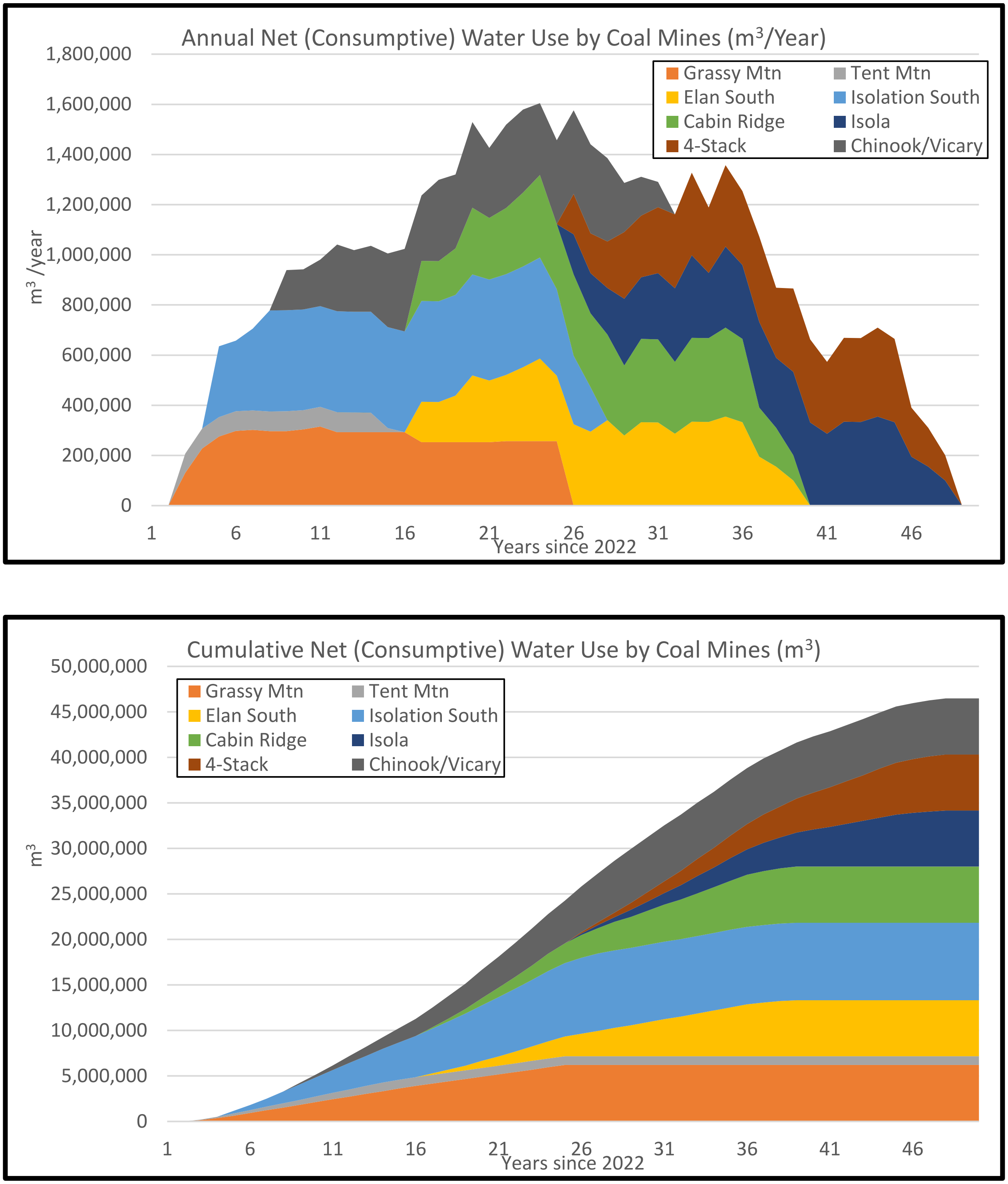


Figure 91. Annual (upper) and cumulative (lower) net water use by coal mines under the High Growth Scenario.

Mine Reclamation Area

In the medium coal development scenario, the amount of reclaimed area increases to 20-30 ha/yr during decades 1 and 2 (Figure 92). Cumulative area reclaimed at the end of the simulation is 400 hectares which approximates 25% of the total disturbed area (Figure 92). In a more practical sense, the cumulative reclamation area is likely to be distributed over a longer period of time.

In the high coal development scenario, the amount of reclaimed area increases to values of 40-70 ha/yr during the full simulation period (Figure 93). Cumulative area reclaimed at the end of the simulation is 2,405 ha which approximates 25% of the total disturbed area (Figure 93). The cumulative amount of area disturbed and reclaimed for the high growth scenario is illustrated in Figure 94.

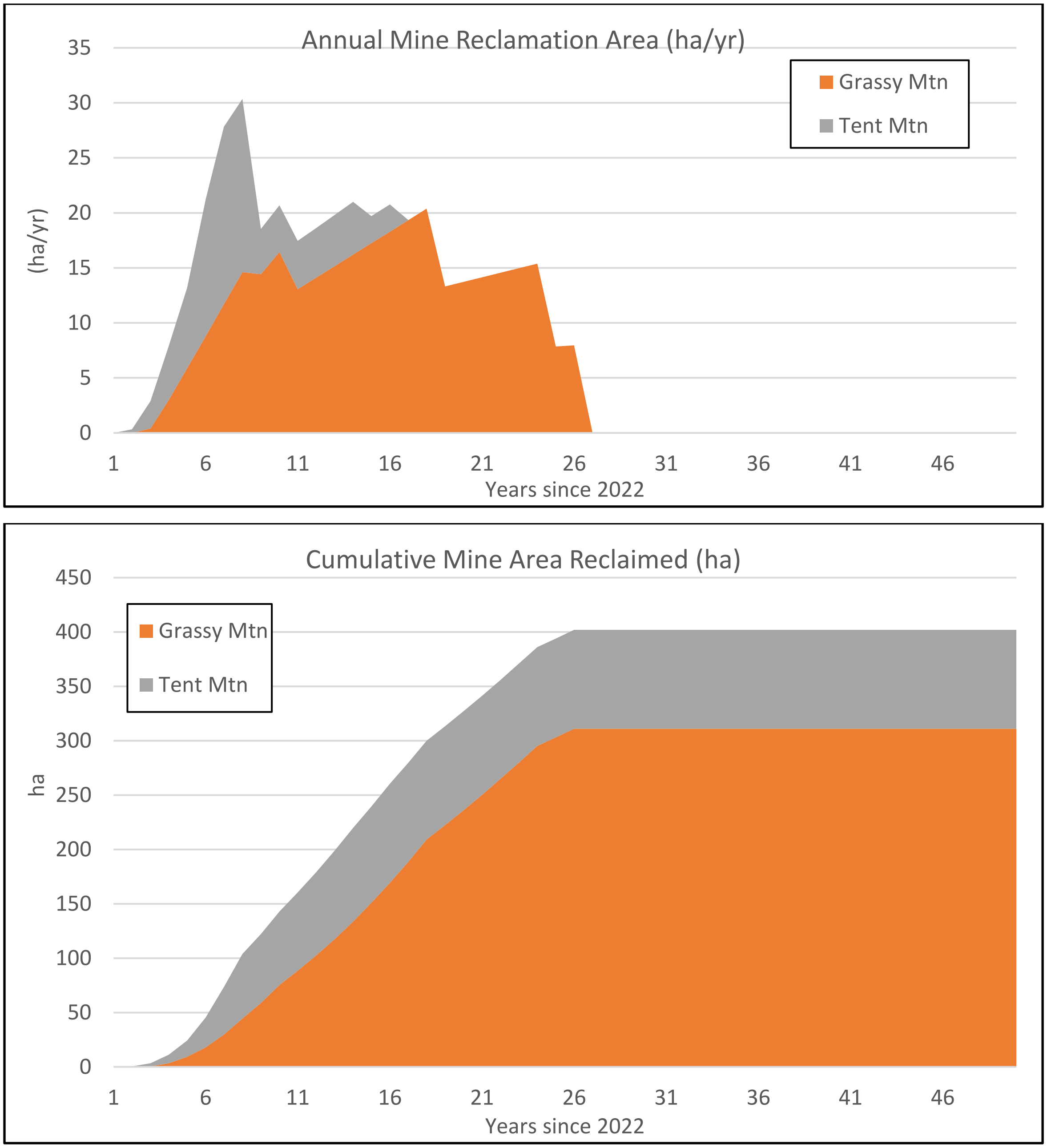
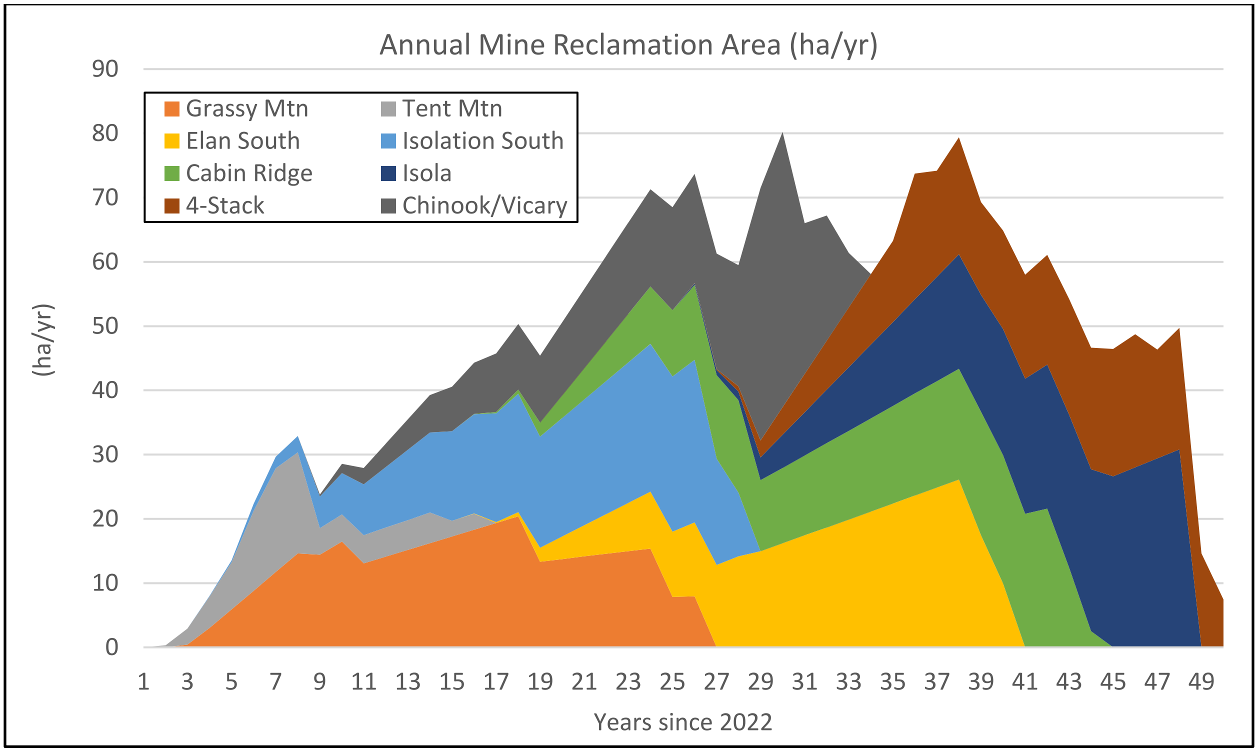


Figure 92. Annual (upper) and cumulative (lower) area (ha) of reclaimed mine site under the High Growth Scenario.



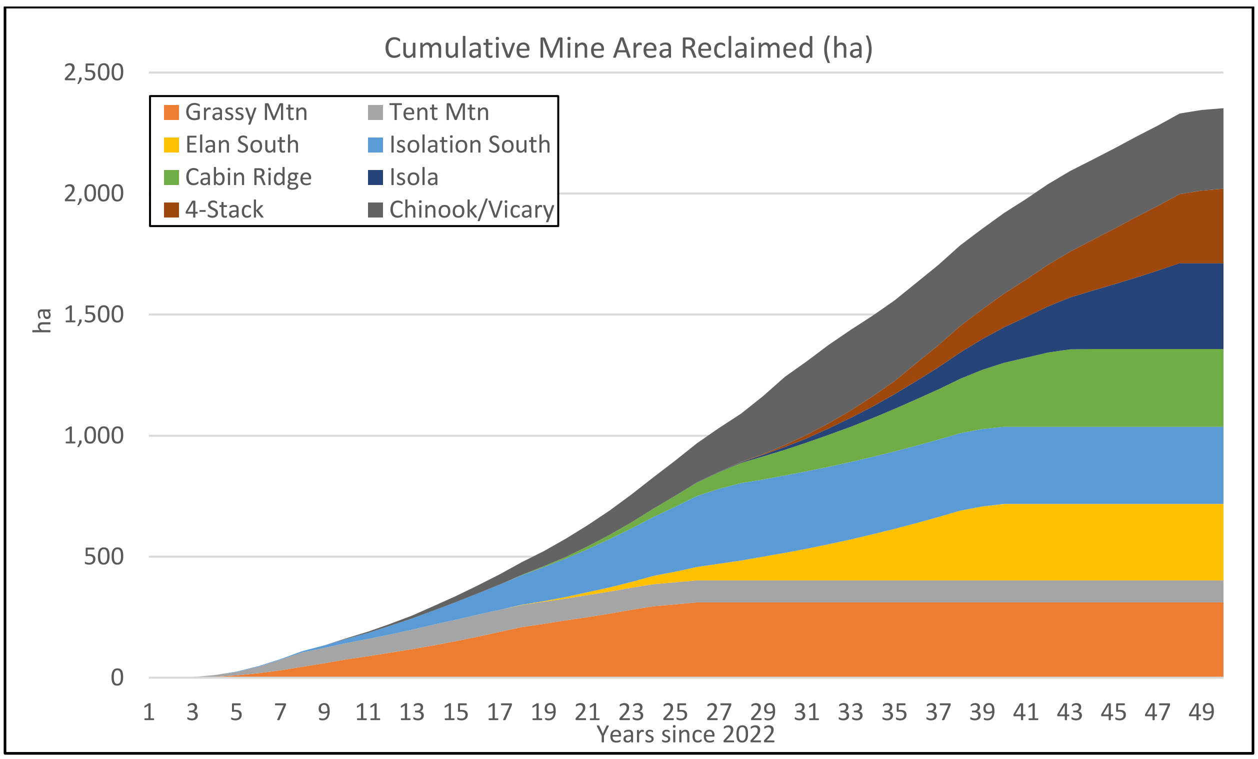


Figure 93. Annual (upper) and cumulative (lower) area (ha) of reclaimed mine site under the High Growth Scenario.

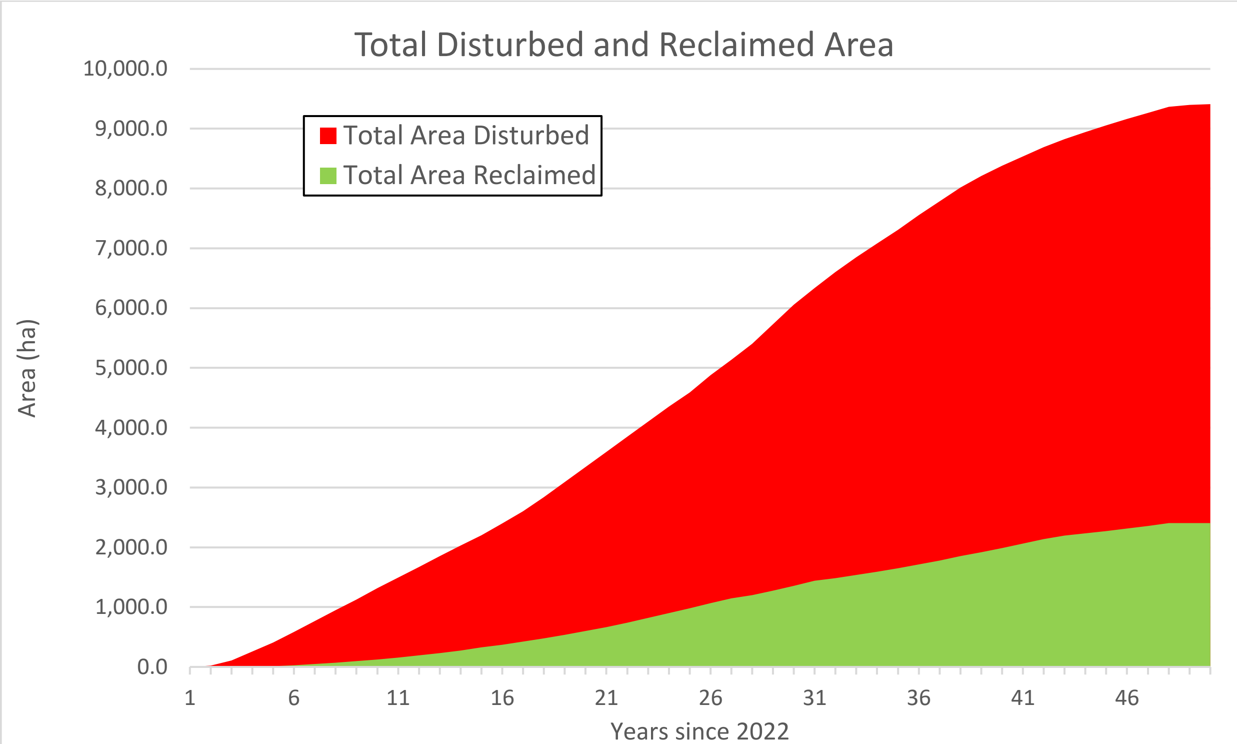


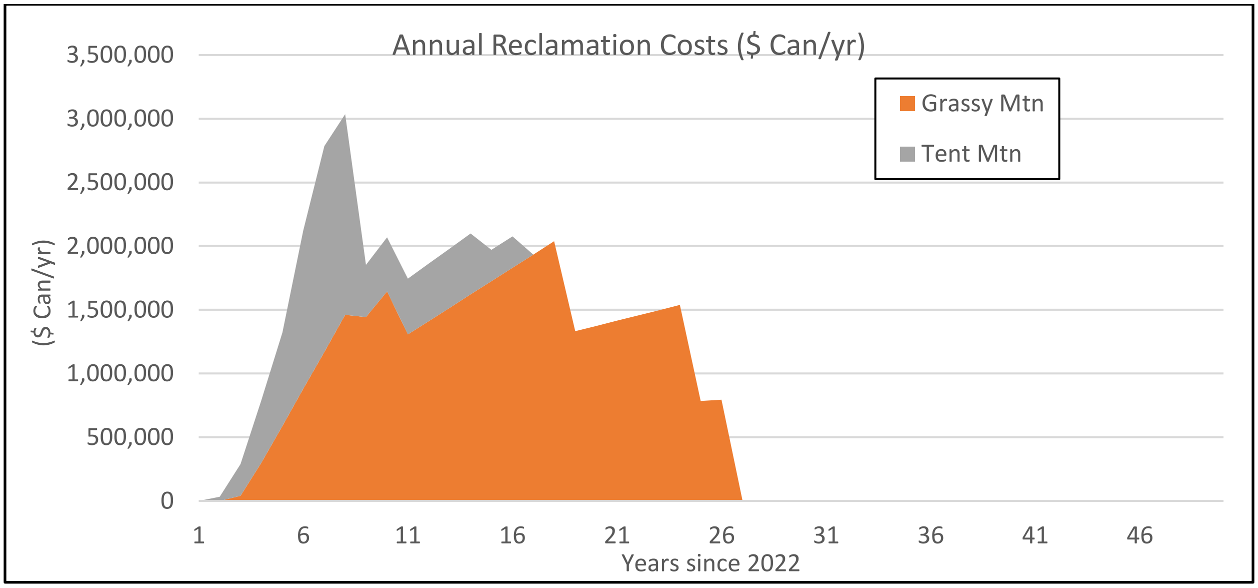
Figure 94. Cumulative area disturbed (red) and area reclaimed (green) for the high growth coal scenario

Mine Reclamation Costs

In the medium coal development scenario, reclamation costs vary between $1.5-3.0 M/yr during decades 1-3 (Figure 95). Cumulative reclamation costs over the simulation are $40 M, which contributes to the reclamation of ~25% of the total disturbed area (Figure 94). In a more practical sense, the cumulative reclamation costs are likely to be distributed over a longer period of time.

In the high coal development scenario, reclamation costs vary between $3-8 M/yr during decades 1-5 (Figure 96). Cumulative reclamation costs over the simulation are $235 M, which contributes to the reclamation of ~25% of the total disturbed area (Figure 94).

There is uncertainty about the actual reclamation costs associated with attaining a defined post-mine reclamation performance. This variance (from $25K/ha (low), to $100K/ha (medium), to $175K/ha (high)) is expressed in Figure 97 (medium growth scenario) and Figure 98 (high growth scenario).



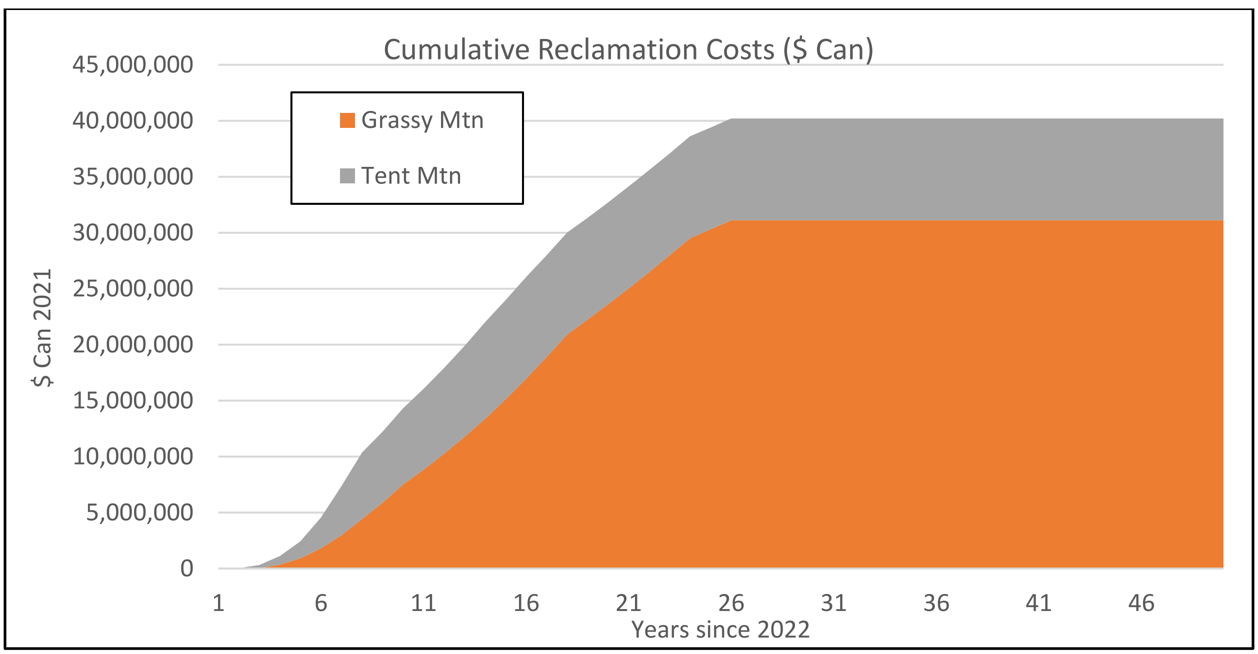
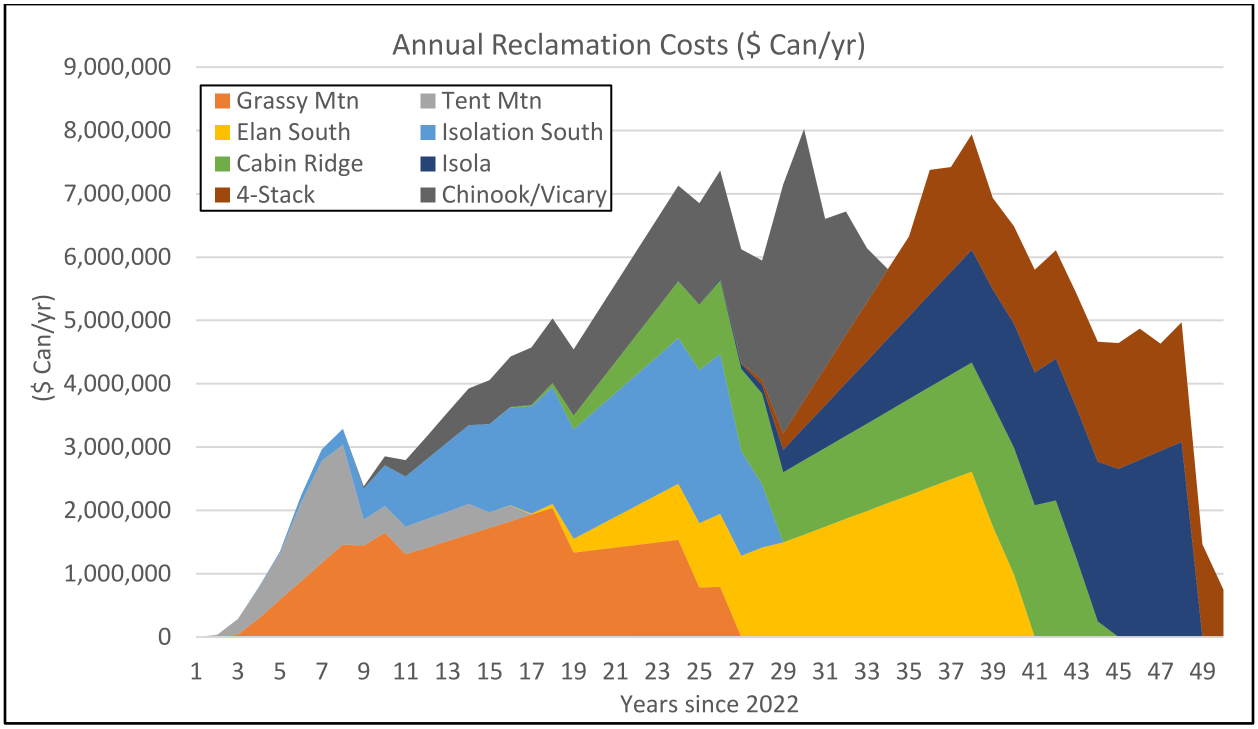


Figure 95. Annual (upper) and cumulative (lower) reclamtion costs ($) under the Medium Growth Scenario.



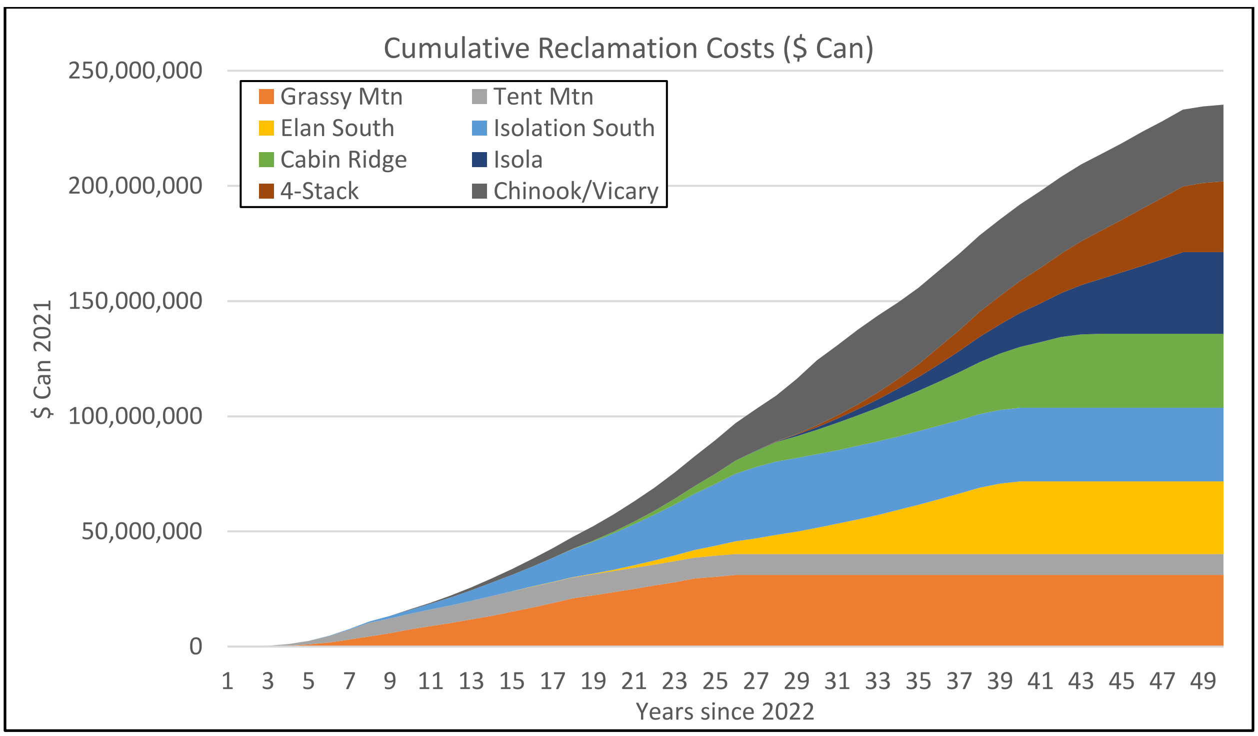
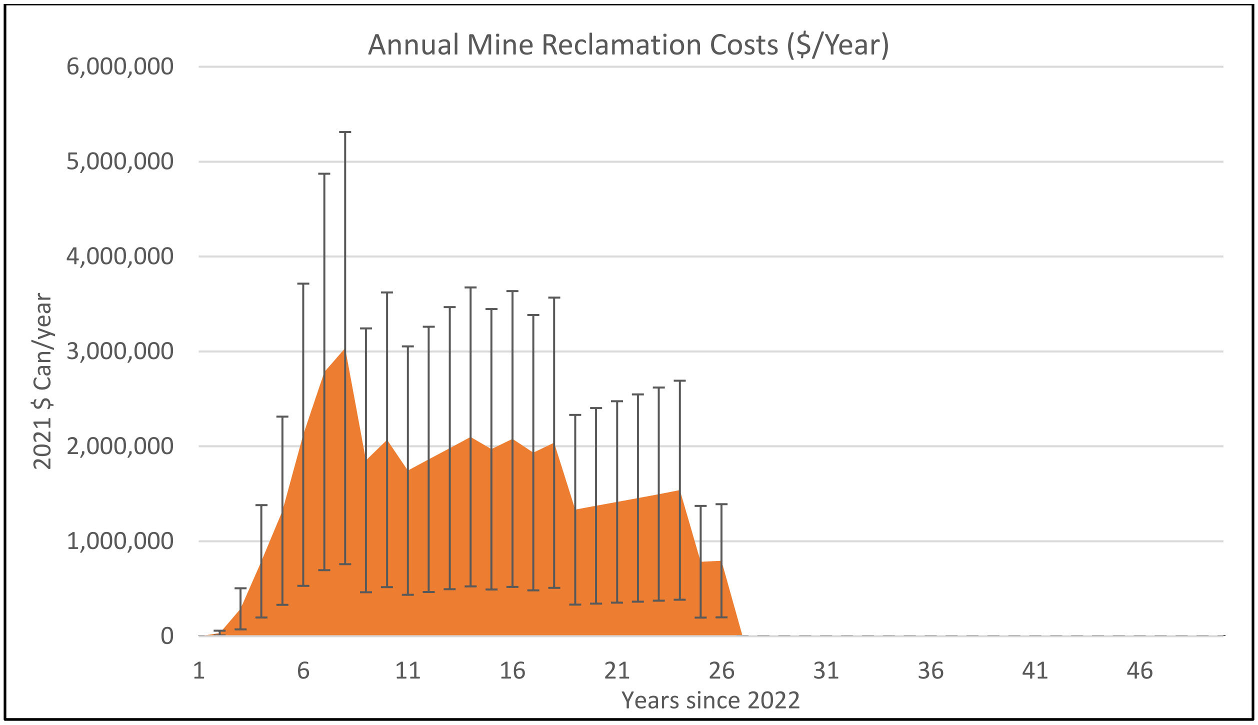


Figure 96. Annual (upper) and cumulative (lower) reclamation costs ($) under the High Growth Scenario. Based on medium reclamation cost estimate of $100,000/ha.



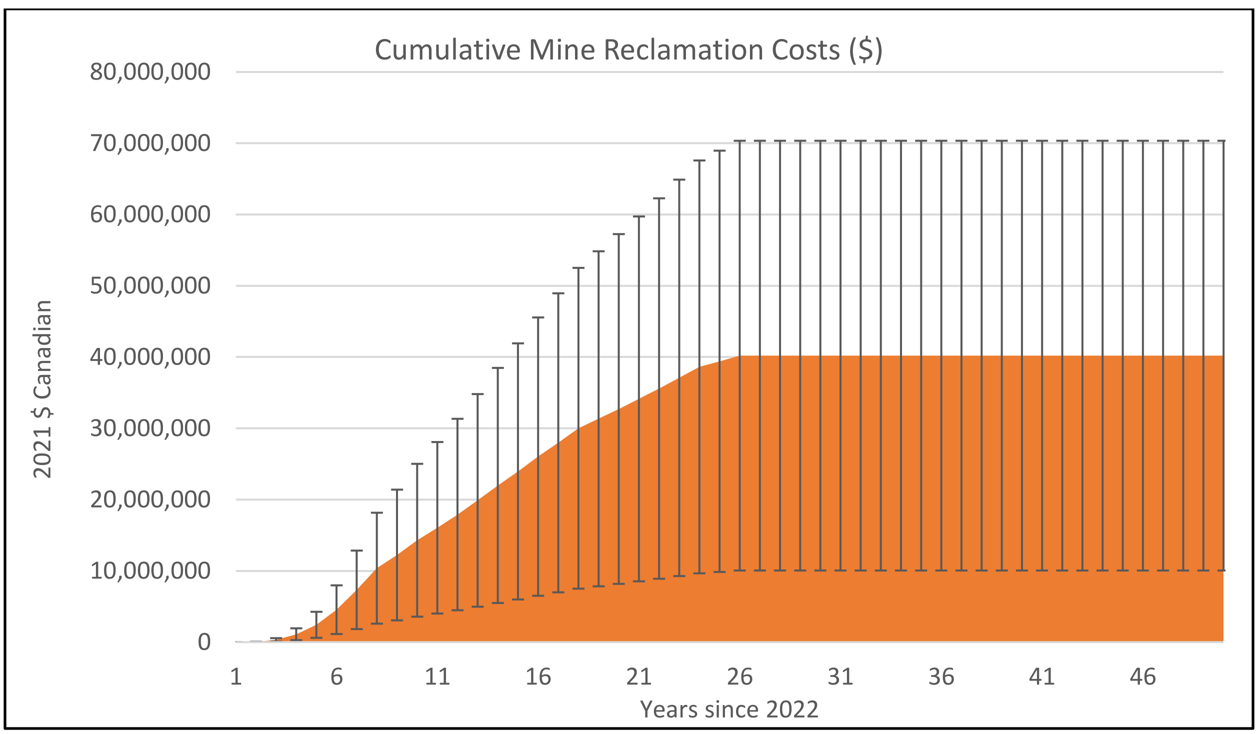
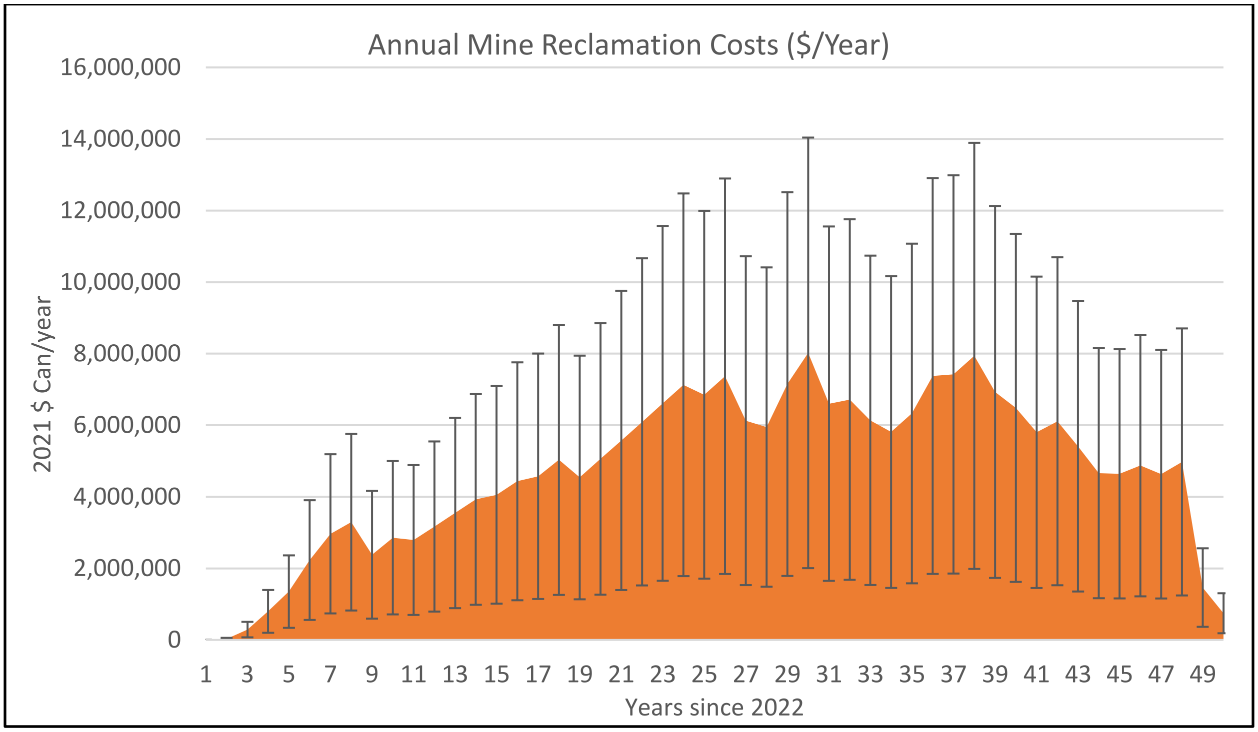


Figure 97. Annual (upper) and cumulative (lower) total reclamation costs with variance estimates under the Medium Growth (only Grassy and Tent Mtn) Scenario. Mean values (orange) reflect average reclamation standards associated with $100,000/ha. Upper bounds reflect high reclamation standards of ~$175,000/ha and lower bounds reflect minimal reclamation standards of $25,000/ha. Note that only 25% of the disturbed area is reclaimed by year 50.



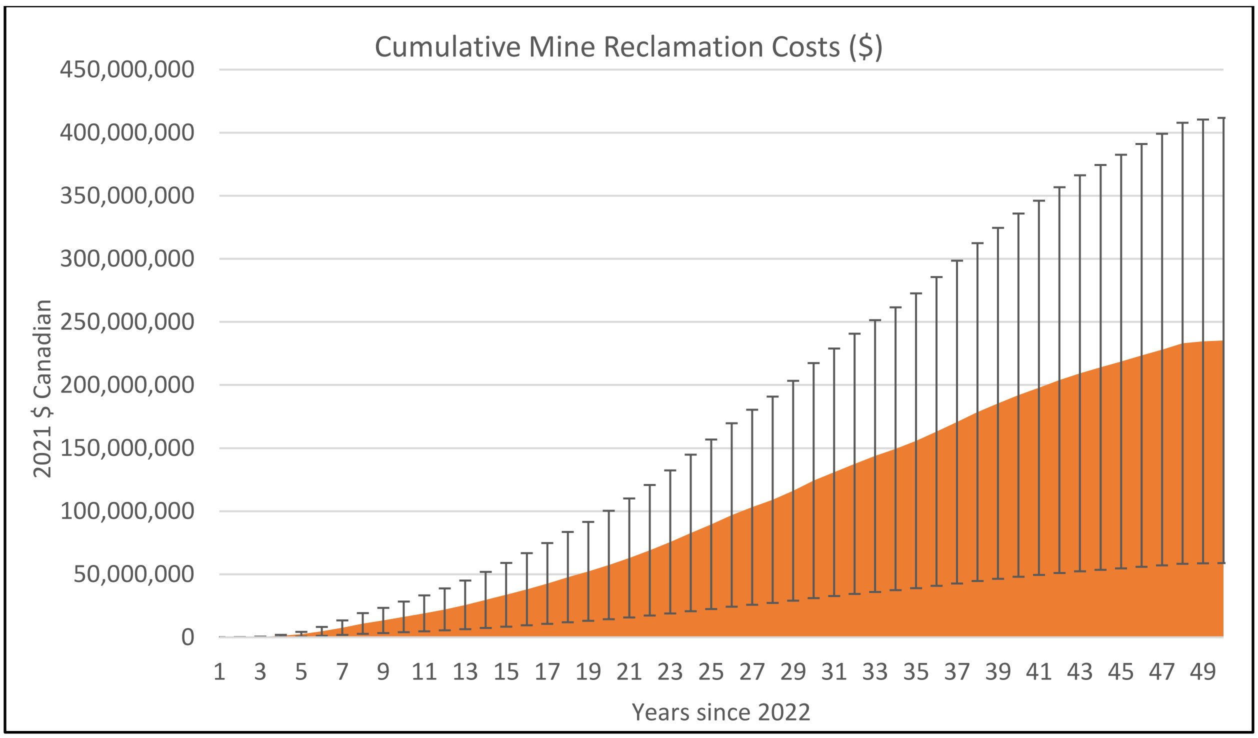


Figure 98. Annual (upper) and cumulative (lower) total reclamation costs with variance estimates under the High Growth (all 8 mines) Scenario. Mean values (orange) reflects average reclamation standards associated with $100,000/ha. Upper bounds reflect high reclamation standards of ~$175,000/ha and lower bounds reflect minimal reclamation standards of $25,000/ha. Note that only 25% of the disturbed area is reclaimed by year 50.

GHG Emissions (full life cycle)

At a maximum coal production rate (Year 10, 2031) of ~5.875 MTA under the medium growth scenario, annual emissions of $C0_2$e are estimated at (5,875,000 tonne x 2.75 (full life cycle, $C0_2$e tonne/tonne of coal production[162]) 16.156 M tonne/year. Over the 50 year life of the 2 mines (Grassy and Tent), a total of 293.4 MT of CO_2e is expected to be emitted. These values might be considered conservative in that fugitive gas emissions (methane) can be comparatively large[163], contribute ~15% of total coal mining-related emissions[164], and these contributions are not considered in these analyses.

At a maximum annual coal production rate of ~23.95 MTA under the high growth scenario, annual emissions of $C0_2$e are estimated at (23,950,000 tonne x 2.75 (full life cycle, $C0_2$e tonne/tonne of coal production) of 65.9 M tonne/year. Over the 50 year life, a total of 1.907 B tonne of CO_2e is expected to be emitted.

For comparison, the total (all sources) annual emission of CO_2e in Alberta has been estimated by the Government of Canada to have grown from 170 to 270 MT from 1990 to 2019 (Figure 99). Relative to the 2019 rate, the addition of the high coal mine scenario in the ORW headwaters would equate to a full life cycle equivalent of ~24% of the current provincial annual emissions. If a high coal mine trajectory is allowed to proceed, the ~693 Million Tonne of coal produced cumulatively would generate ~1.9 B tonne of $C0_2$e (full life cycle). At a time where both Canada and Alberta[165] have made binding agreements to reduce CO_2e emissions, this increase associated with a new coal mine trajectory in Alberta's East Slopes will only make achieving these goals more challenging, if not impossible.

In the medium coal development scenario, greenhouse gas emissions ($C0_2$e tonne/year; full life cycle) vary between 10-14 M tonne/yr during decades 1-3 (Figure 100). Cumulative emissions over the simulation are 293 M tonne. In the high coal development scenario, greenhouse gas emissions ($C0_2$e tonne/year; full life cycle) vary between 25-60 M tonne/yr during decades 1-5 (Figure 101). Cumulative emissions over the 5-decade simulation are 1.91 B tonne.

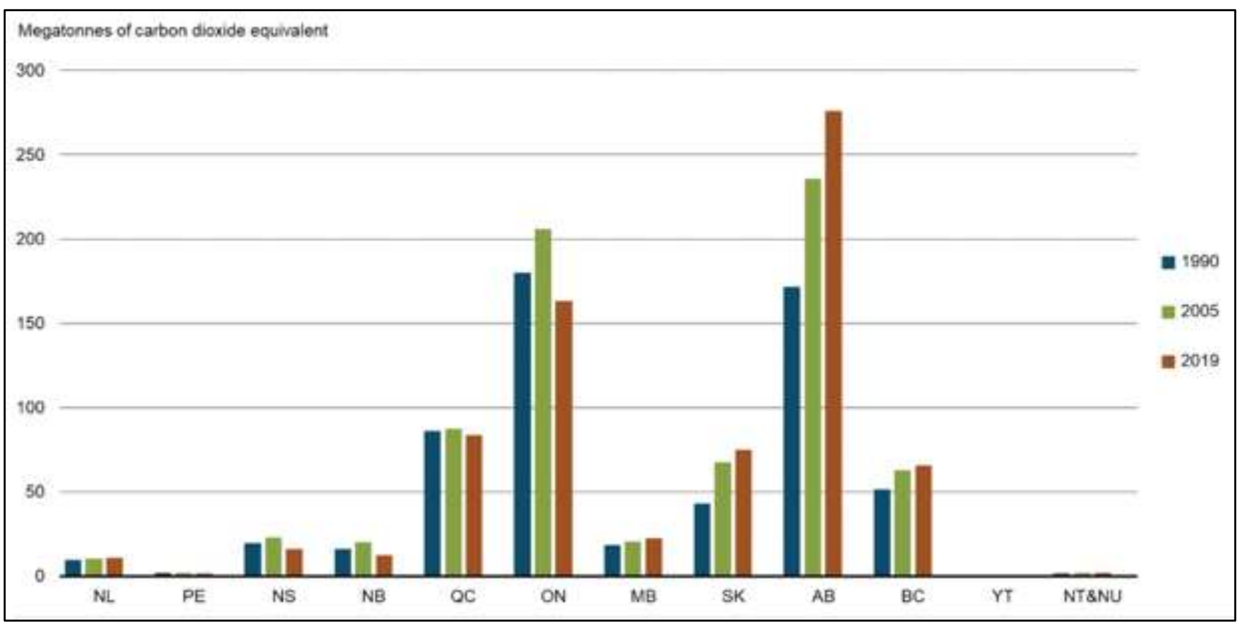
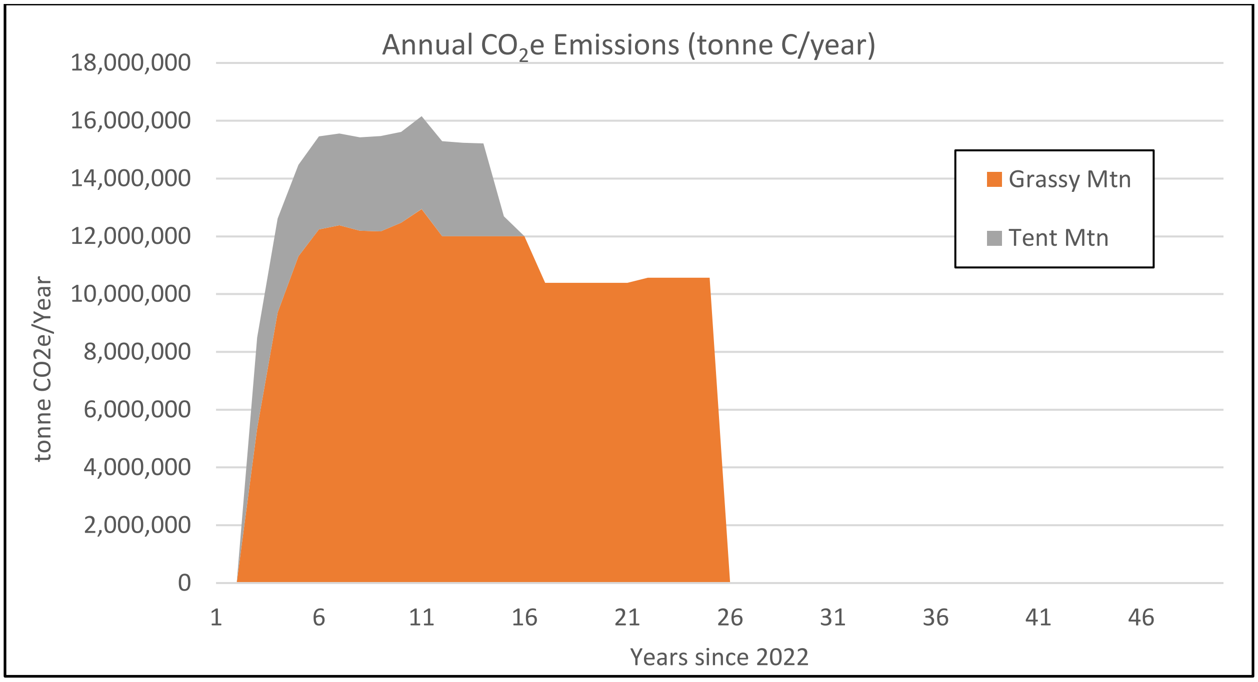


Figure 99. Annual GHG emissions in Alberta for 1990, 2005, and 2019, and in comparison, to other jurisdictions. Source: https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions.html



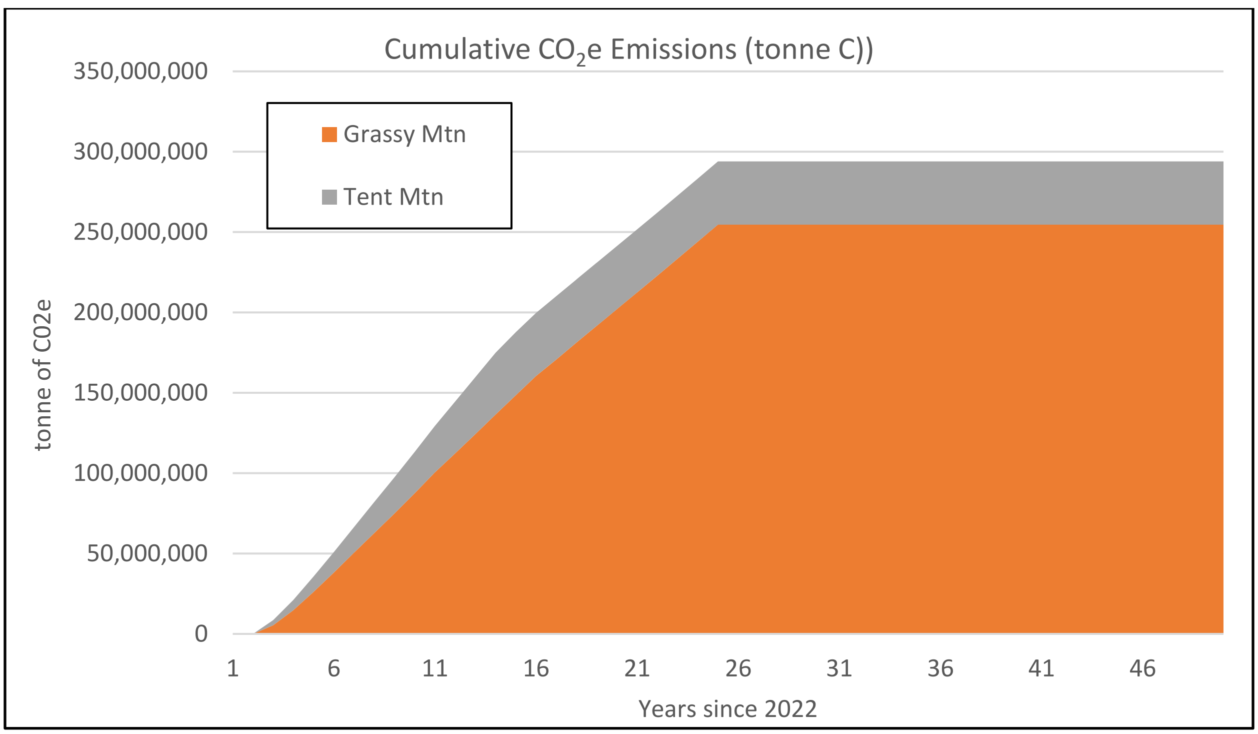
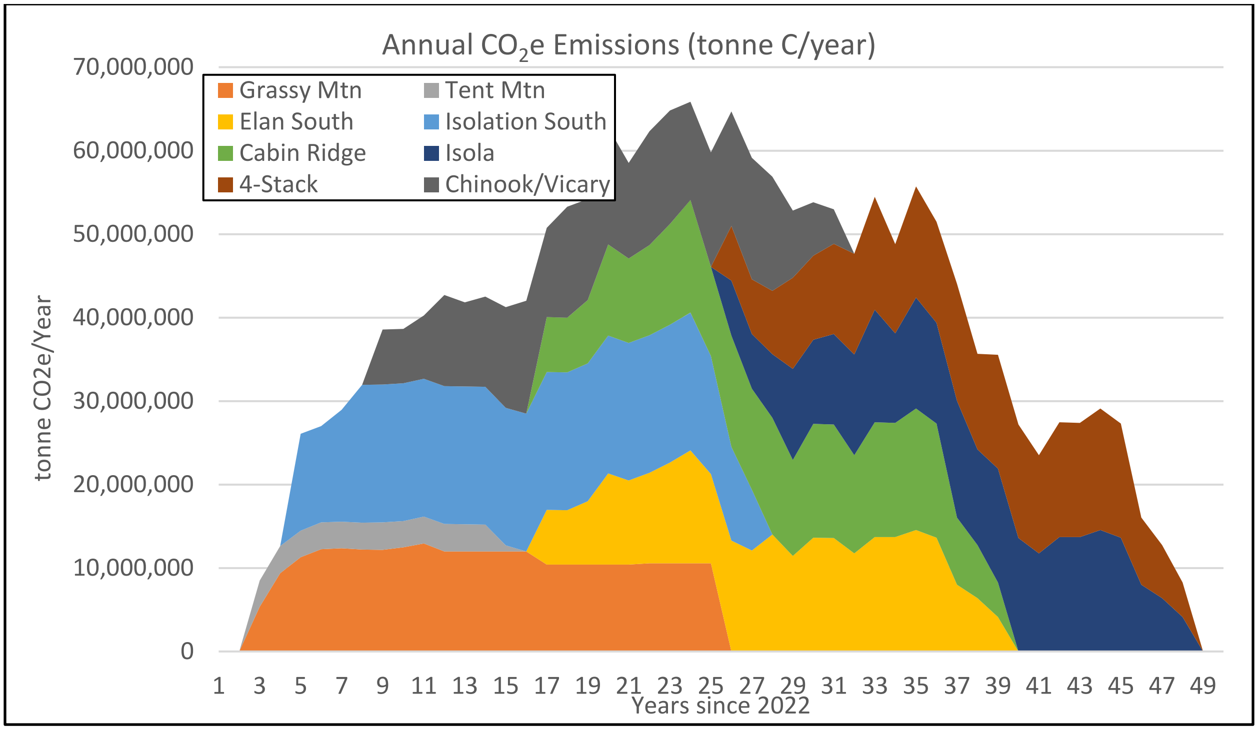


Figure 100. Annual (upper) and cumulative (lower) CO_2e emission (full life cycle) under the High Growth Scenario.



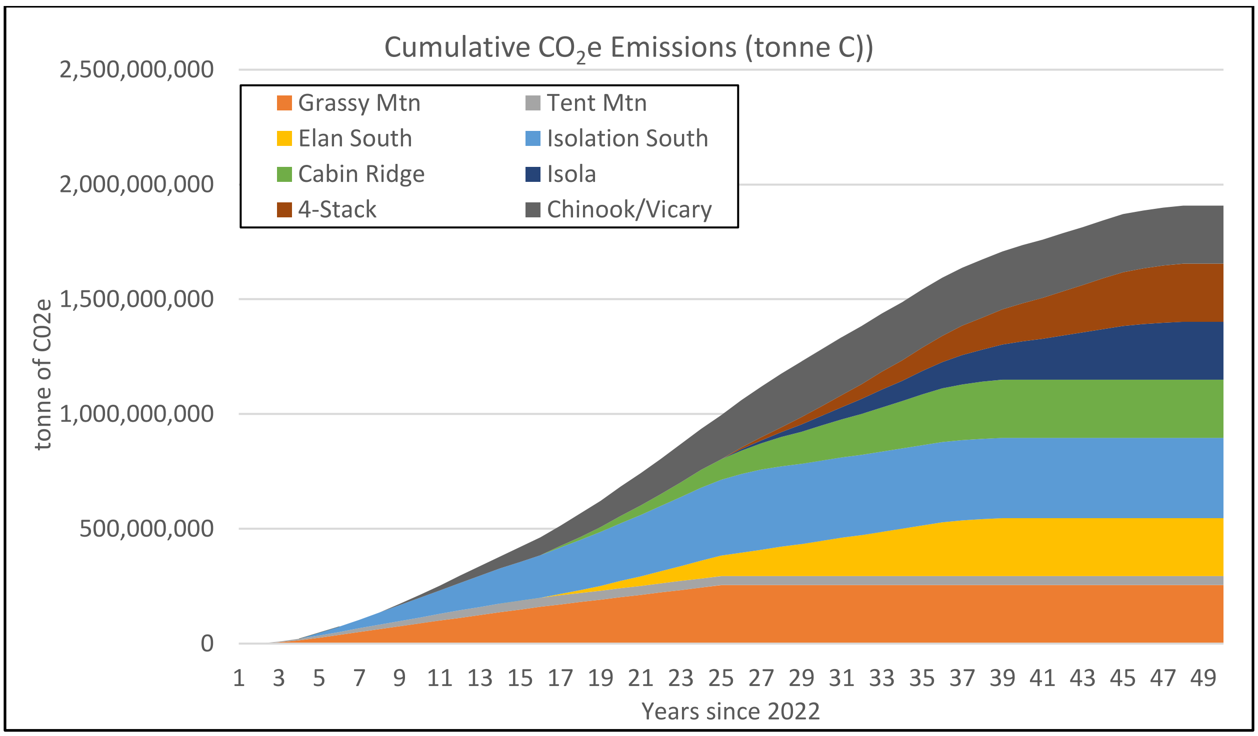


Figure 101. Annual (upper) and cumulative (lower) CO_2e emission (full life cycle) under the High Growth Scenario.

The Loss of Headwater Streams and Riparian Corridors.

Though small, headwater streams and their adjacent riparian habitats play a critical regulatory function in conserving water flow, water quality, aquatic invertebrates, and native fish species, either directly or indirectly[166]. These natural capital values include, or are affected by, the key indicators (water supply, selenium, Westslope cutthroat trout) examined by this study. In the majority of cases, the proposed coal mines in the ORW occur in the headwater basins and at these locations streams are small and often intermittent. Examples of the small scale of these lotic and riparian systems are shown below (Figure 102).

The maps (Figure 103 - Figure 110) below show the current distribution of riparian habitat (inclusive of the streams themselves and a 50 m buffer) in each of the 8 prospective surface mine sites. The original lotic spatial data is from the 2018 ABMI dataset[167]. The analyses below suggest that ~1/3rd of all area within the coal mining disturbance footprint can be defined as riparian habitat (Table 8). A minimum of 3,213 ha of streams and their adjacent riparian habitat will be removed by the activities of surface coal mining. Although examining the precise mechanisms within the coal sites that cause mining to affect water flow, water quality, and salmonid populations and habitat were beyond the scope of this project, the adverse consequences are widely understood[198].

Both WSCT[168] and Bull Trout [169] are classified as "Threatened" by the Government of Alberta, and these headwater streams and their associated riparian habitat play important roles in the life history of these endangered trout species[170].

Figure 102. Examples of small and intermittent streams from the headwaters of the ORW in the vicinity of proposed coal mines. Photo Credit: Lorne Fitch.

Table 8. Area of riparian habitat within the active mining area of 8 prospective coal mines based on a 50 m buffer placed on surface lotic (moving) features within the simulated cumulative mined site.

Prospective Coal Mine	Estimated Riparian Area (ha)	Total Simulated Area Disturbed (ha)	Fraction
Grassy Mountain	576	1,244	0.463
Tent Mountain	45	364	0.124
Cabin Ridge	538	1,276	0.422
Elan South	484	1,261	0.384
Isolation South	464	1,278	0.363
Isola	415	1,354	0.306
4-Stack	306	1,235	0.248
Chinook / Viccary	385	1,334	0.289
Total	**3,213**	**9,346**	**0.344**

*Note that some of the initial riparian habitat on each of Grassy Mountain and Tent Mountain have been removed by mining activities associated with legacy coal mines.

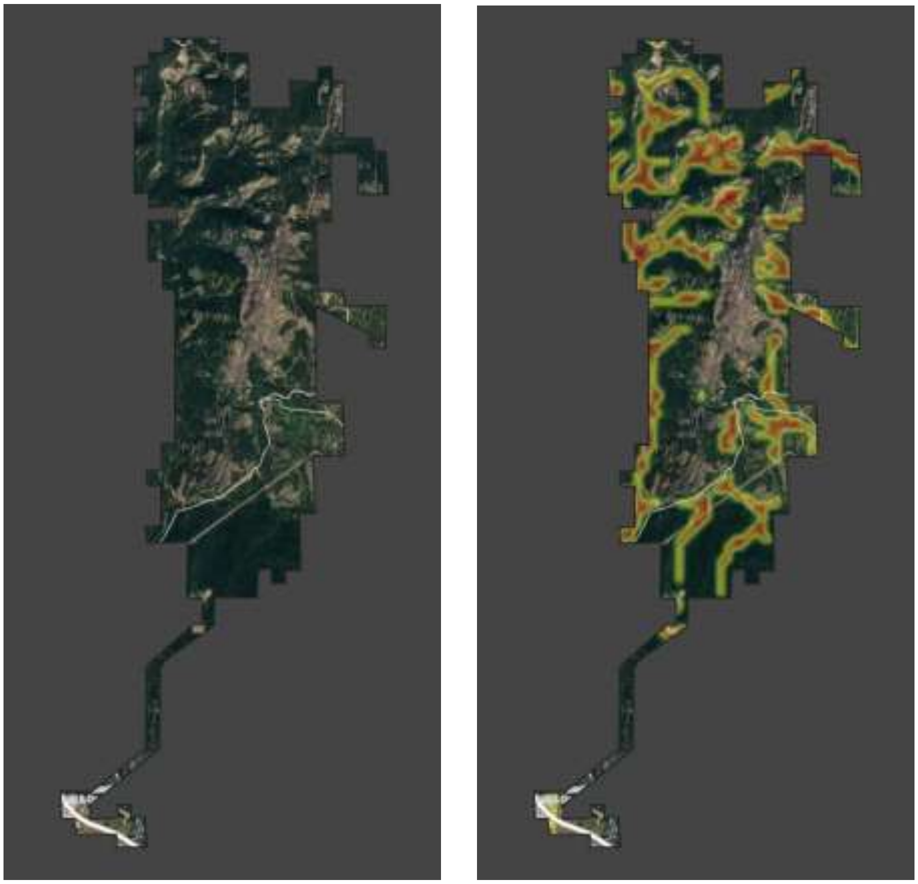


Figure 103. Grassy Mountain prospective Mine Site showing the distribution of stream riparian buffers (50 m) from surface lotic features. Some riparian habitat is missing because of historic mining from legacy coal mining activities.

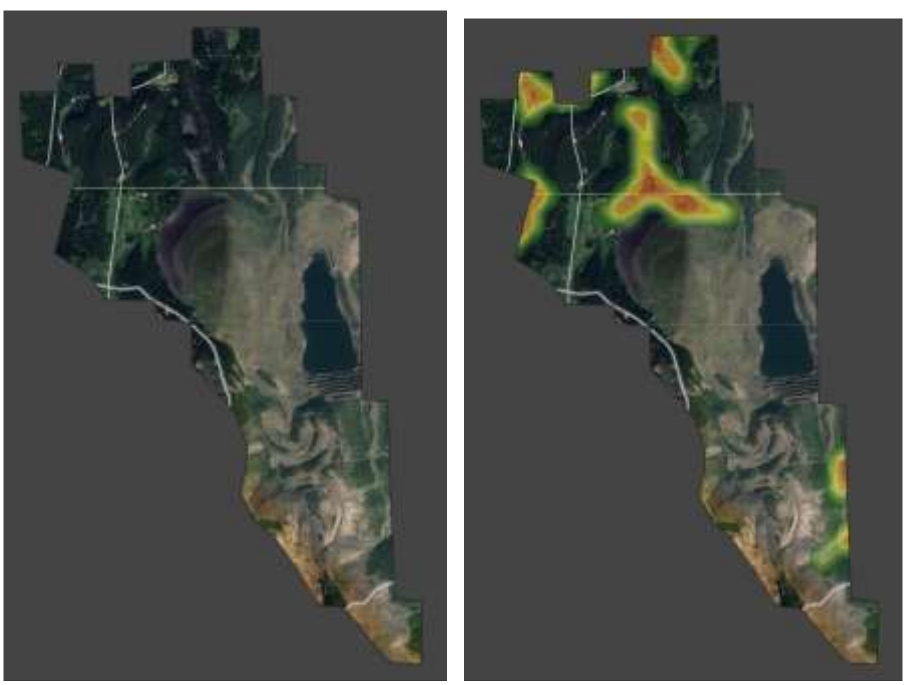


Figure 104. Tent Mountain prospective mine site showing the distribution of stream riparian buffers (50 m) from lotic features. Some riparian habitat is missing because of historic mining from legacy coal mining activities.

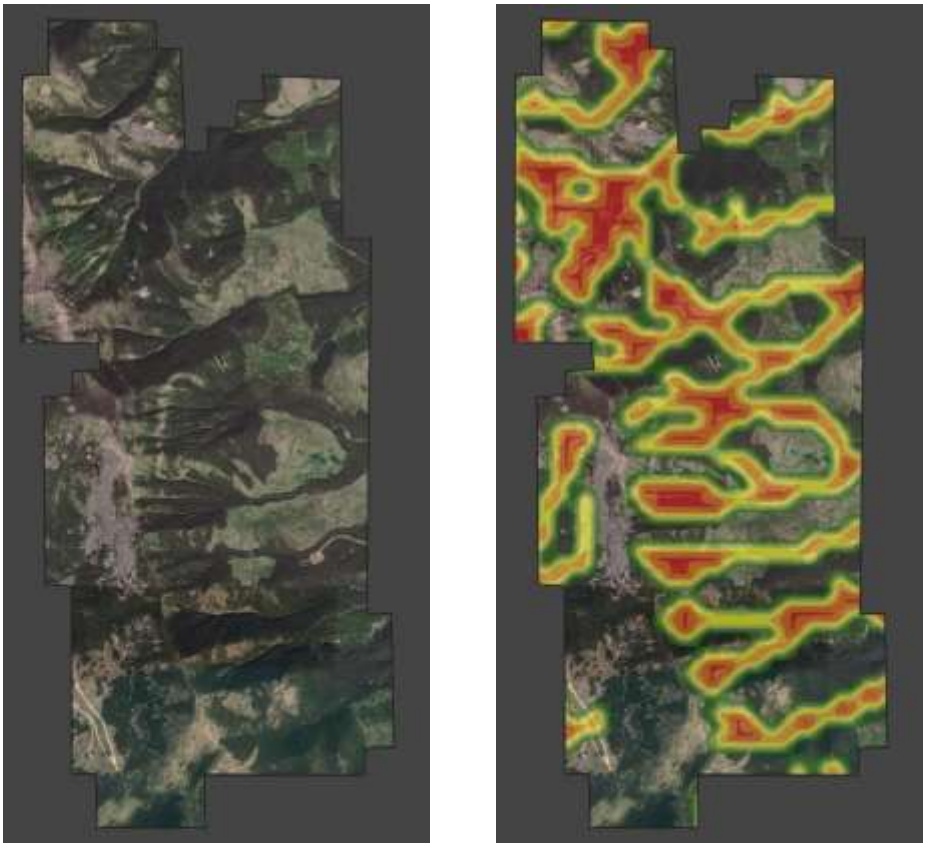


Figure 105. Isolation South prospective mine site showing the distribution of stream riparian buffers (50 m) from lotic features.

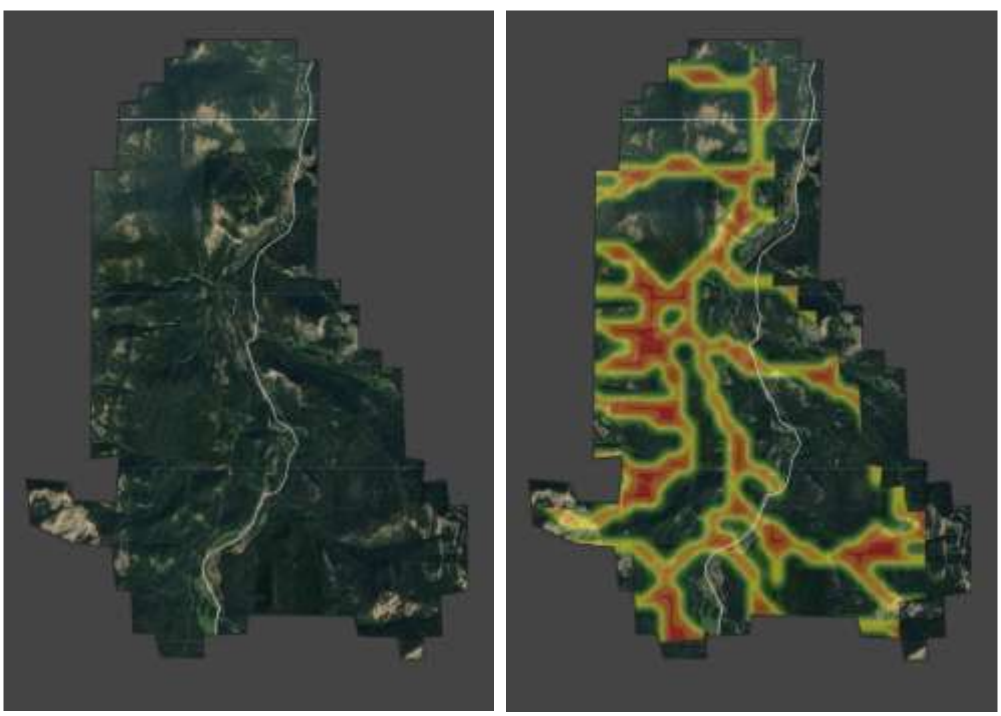


Figure 106. Elan South prospective mine site showing the distribution of stream riparian buffers (50 m) from lotic features.

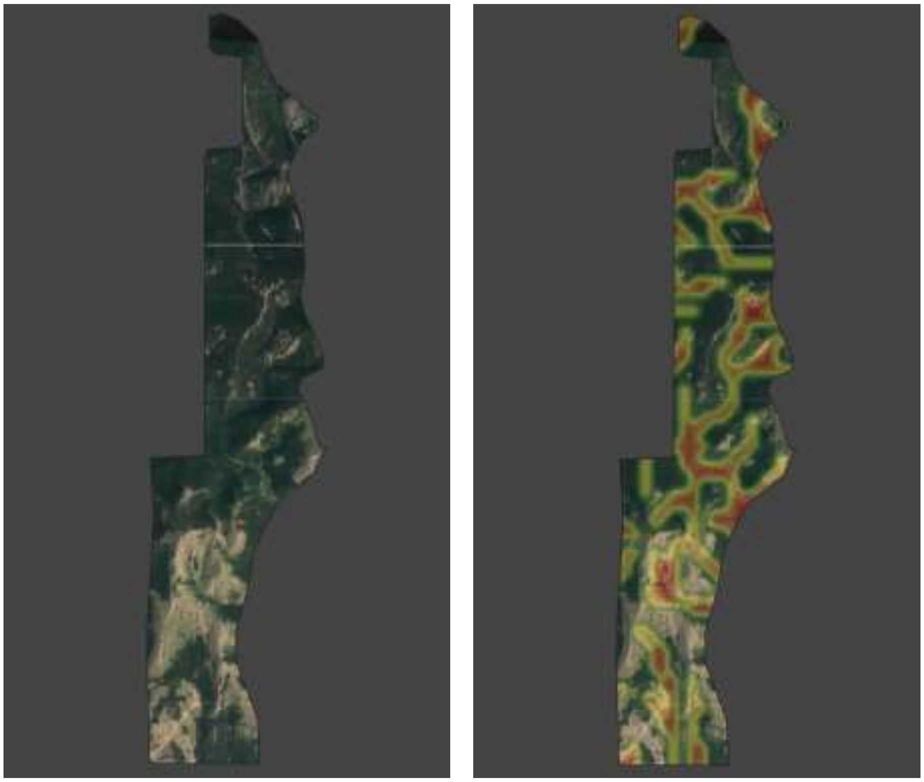


Figure 107. 4-Stack prospective mine site showing the distribution of stream riparian buffers (50 m) from lotic features.

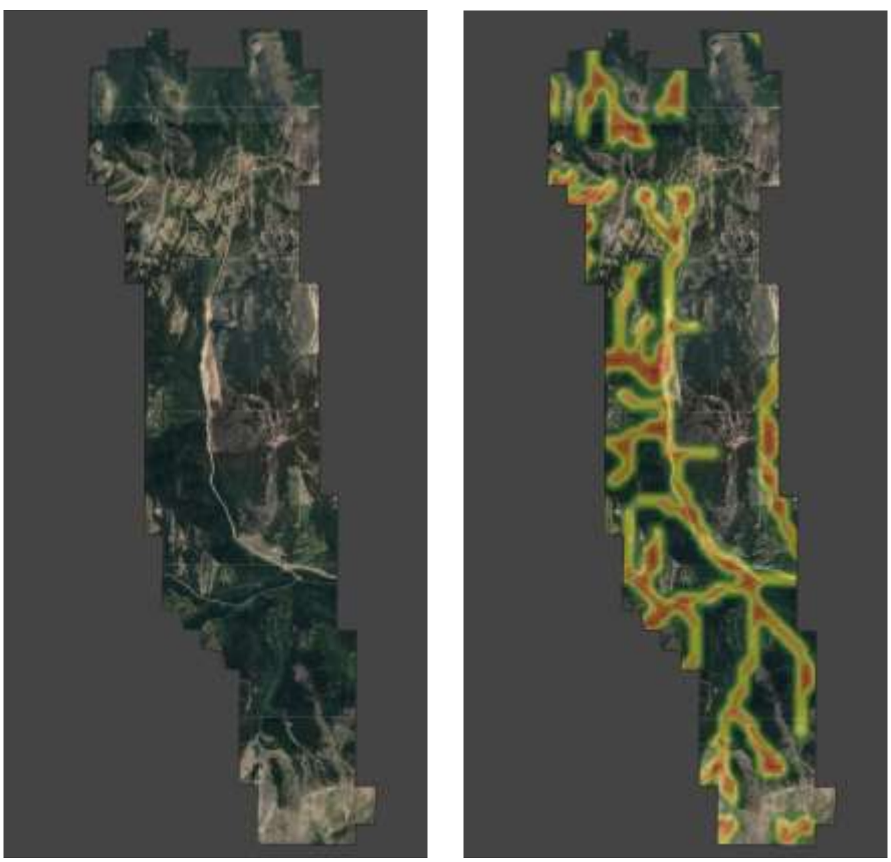


Figure 108. Chinook/Vicary prospective mine site showing distribution of stream riparian buffers (50 m) from lotic features.

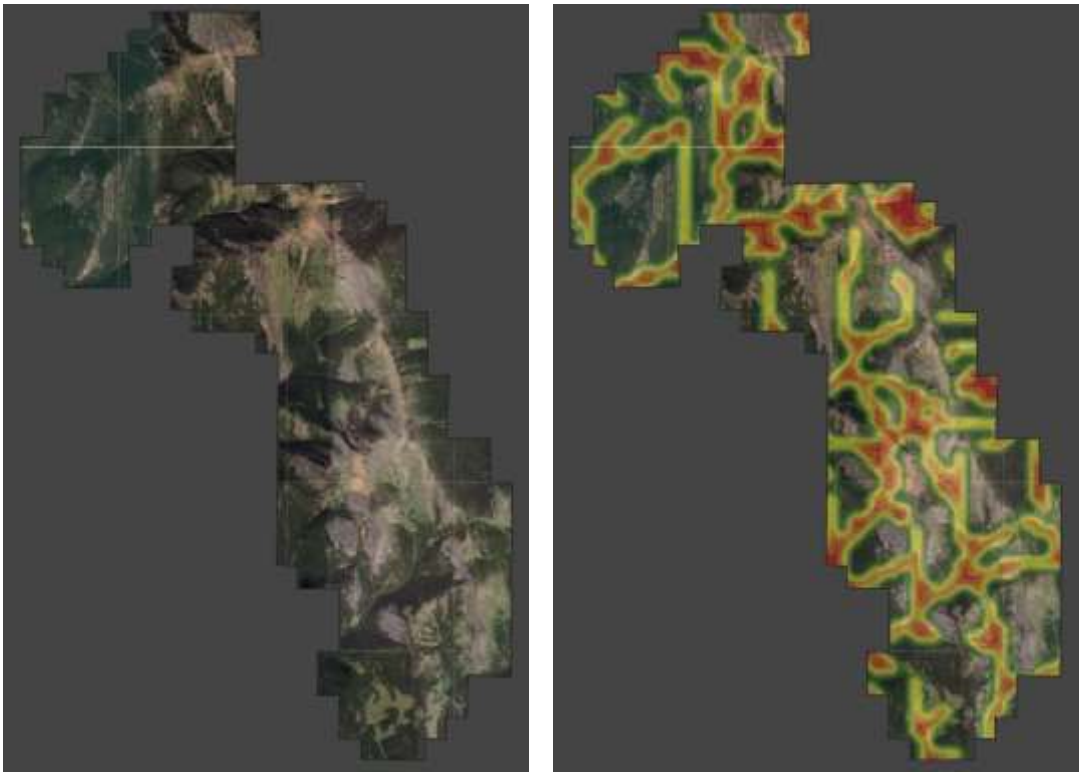


Figure 109. Cabin Ridge prospective mine site showing the distribution of stream riparian buffers (50 m) from lotic features.

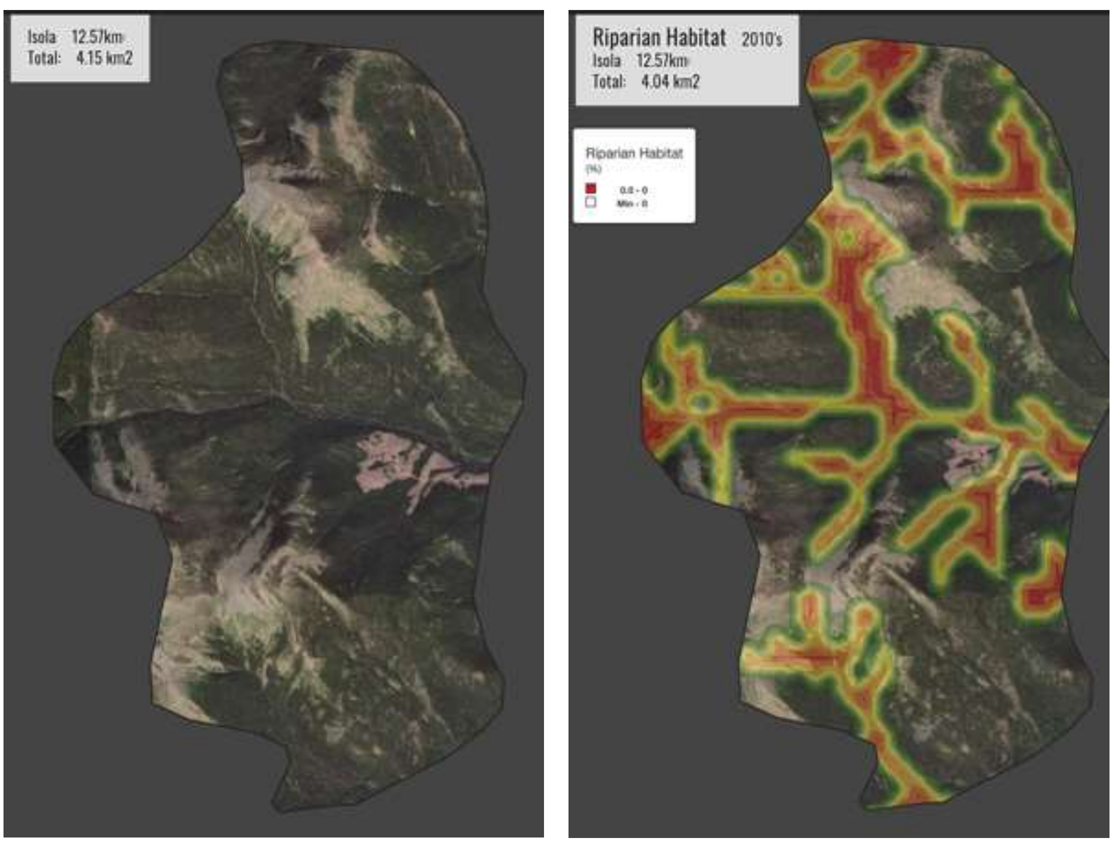


Figure 110. Isola prospective mine site showing the distribution of stream riparian buffers (50 m) from lotic features.

Hydrological Modelling

The objectives, methods, analyses and conclusions of hydrological modeling of this project are presented in the technical document of Chernos et al 2021. What follows is a synopsis of these findings.

The Oldman River Watershed (ORW) is an important water source, supplying agricultural, municipal, industrial, and environmental services for much of southern Alberta. Since the area is relatively arid and streamflow in the ORB is highly allocated, the basin is vulnerable to water shortages and managers can be faced with difficult water management decisions. Climate change is likely to further exacerbate these challenges due to changes in the timing and magnitude of streamflow in the basin. In addition, recent interest in the development of open-pit metallurgical coal mines in the ORW headwaters is likely to place additional demands on water use and has the potential to affect water quality.

The goal of this work was to provide a broad perspective on the variability of water resources in the ORW and outline the potential increase in risks to sustainable water management in the coming decades. The work first outlines the long-term historical risk of 'worst-case' droughts, developed from the instrumental record and a tree-ring reconstructed proxy record compared to current water demand. Second, a hydrological model of the upper ORW was developed to simulate streamflow for tributaries and the Oldman River under a recent historical period (1989-2019) and to estimate streamflow under two future climate change scenarios (RCP 4.5 and RCP 8.5). Third, we applied the model in an integrated manner to evaluate water use and selenium loading associated with two future mine development scenarios to estimate changes to water quantity and quality in the watershed. These results provide a quantitative estimate of potential changes in water supply and water quality because of climate change and proposed open-pit coal mining in the ORW.

Findings from this study demonstrate that streamflow in the ORW originates disproportionately from its mountain headwaters (Figure 111), while by comparison, lower elevation sub-basins located further east and south produce less than half as much runoff. Streamflow in the Oldman River follows a strongly snowmelt-driven pattern, with high flows coinciding with peak snowmelt and greater rainfall in the spring, and low flows during the late summer and winter months. Instrumental records do not show the full range of variability in water supply, and water resource managers must consider less certainty and stationarity, particularly in a basin where water supply challenges are likely based on the longer-term paleohydrological record. In addition, under future climate change scenarios, warmer air temperatures are likely to lead to less winter precipitation falling as snow, and earlier spring snowmelt (Figure 112). These factors lead to higher winter streamflow, an earlier spring peak, and substantially reduced late summer and fall flows. In most sub-basins, the mean annual flow (i.e. the amount of streamflow produced in a year) is projected to increase; however, this increase is greatest along the low elevation sub-basins, while some headwaters sub-basins are projected to see decreases in mean annual flow, in addition to increased volatility in water supply at an annual timescale (Figure 112, Figure 113). By comparison, mean summer flow is projected to decrease in most sub-basins in the coming 30 years (2021-2050), while all portions of the upper ORW are projected to experience declining summer flows by the second half of the century (Figure 114).

Consumptive water use projected from mine development scenarios is relatively small at the scale of the ORW but is a substantial proportion of winter flows in major tributaries, where many mines are likely to be located (Figure 115). There is additional risk of greater reductions in streamflow if a low-flow year coincides with peak mine development and/or if consumptive water use is higher than currently estimated, since water allocations are approximately three times higher. Simulations of mine development suggest that selenium concentrations may exceed water quality guidelines without substantial mitigation measures (Figure 116, Figure 117, Table 9). Headwater tributaries are particularly sensitive to water quality degradation since they bear the full brunt of selenium loading but contain relatively little streamflow to aid in dilution. Likewise, water use from mining operations is likely to be largely concentrated in these same headwater sub-basins, where they make up a greater portion of streamflow, and would exacerbate water quality concerns (Figure 116, Figure 117, Table 9). A strong reliance on mitigation technologies (i.e., selenium attenuation) would be required to maintain adequate water quality if mine development were to take place.

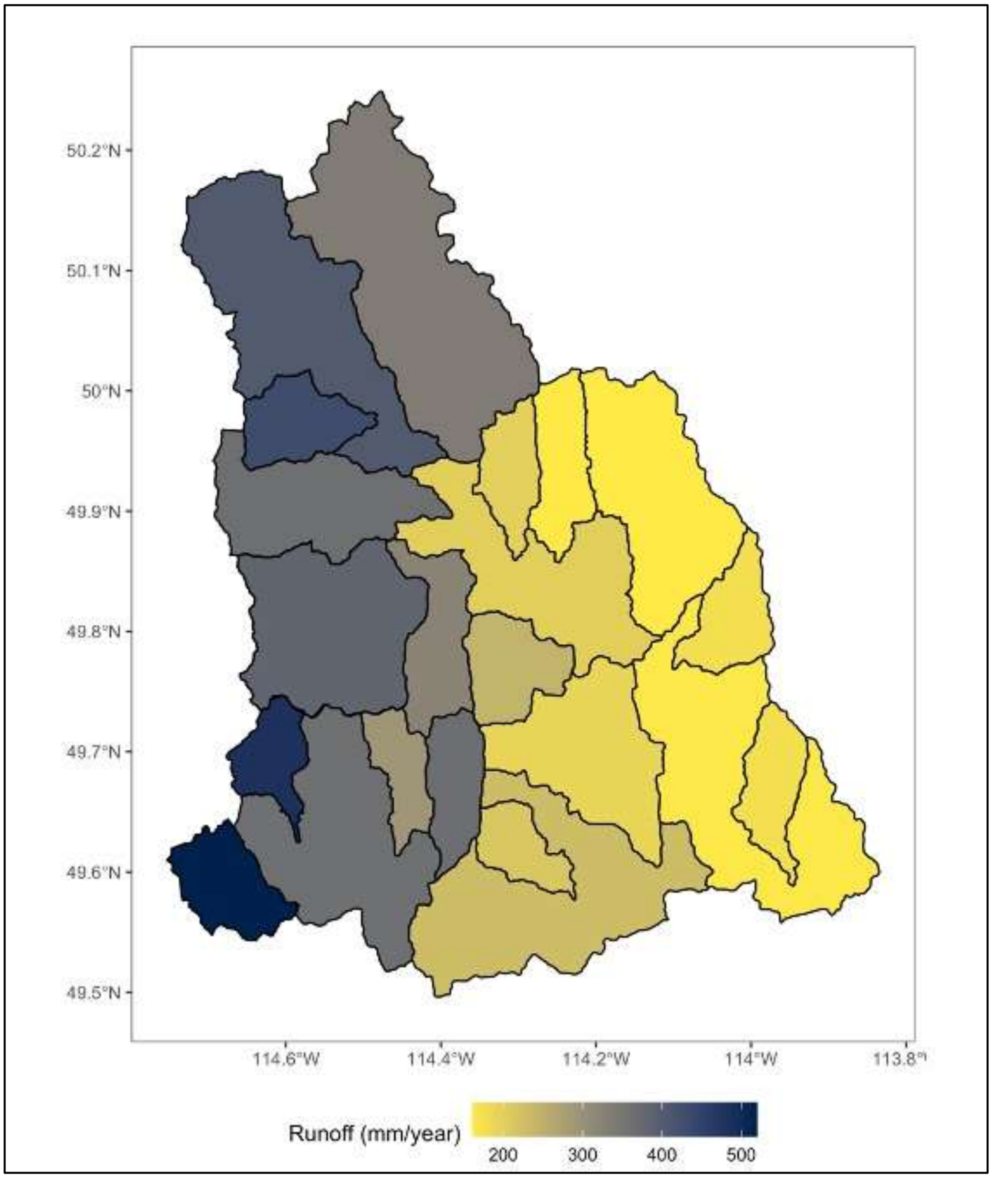


Figure 111. Simulated runoff, averaged over the 1990-2019 period by sub-basin. Source: Chernos et al. 2021.

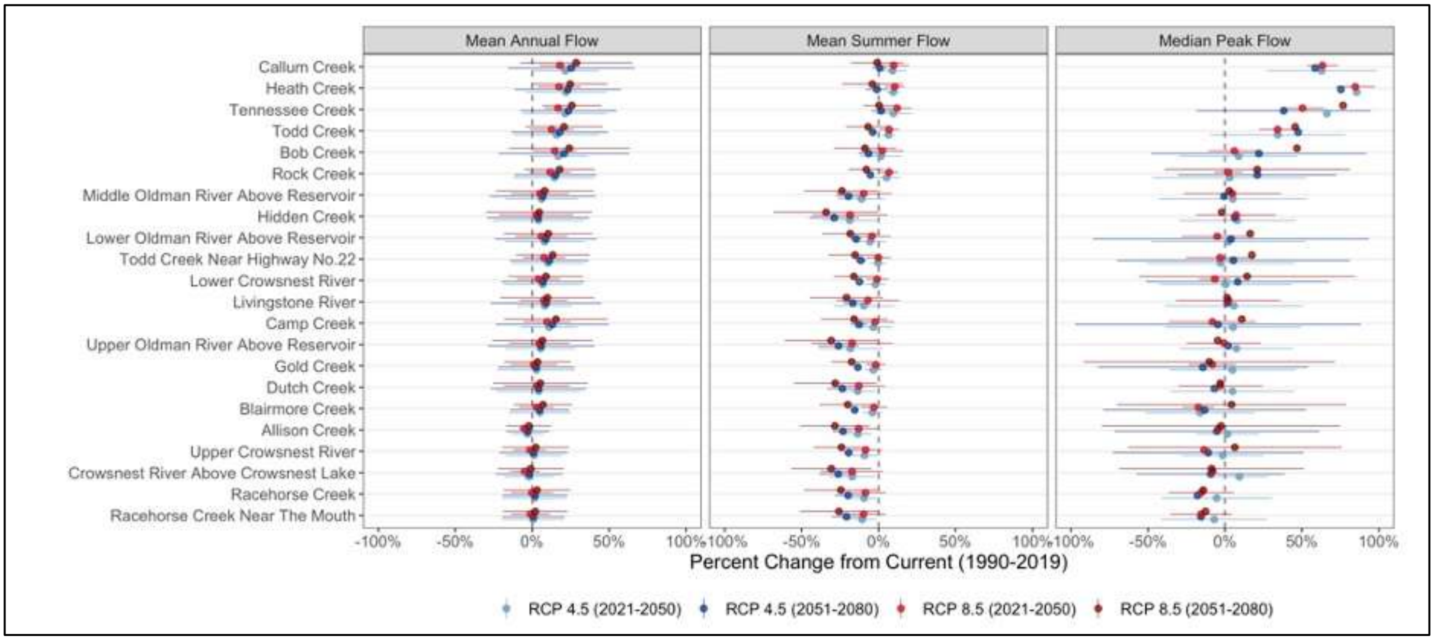


Figure 112. Percent change in mean flow under different climate change scenarios. Points correspond to average change, relative to 1990 to 2019, while lines represent standard error of the estimate. During the critical summer flow period, flow declines significantly under all climate change scenarios.

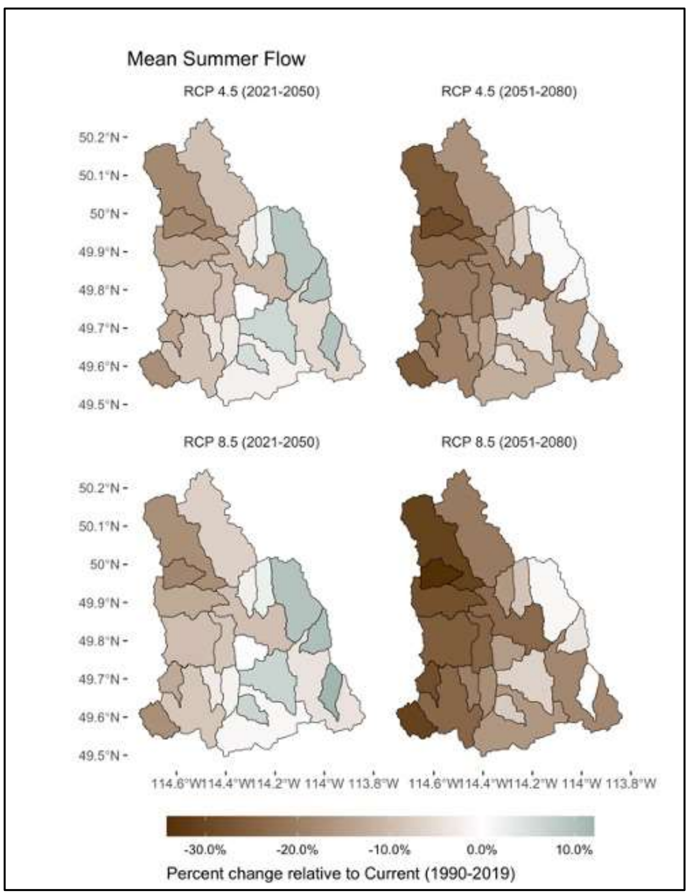


Figure 113. Percent change in Mean Summer Flow relative to Current (1990-2019).

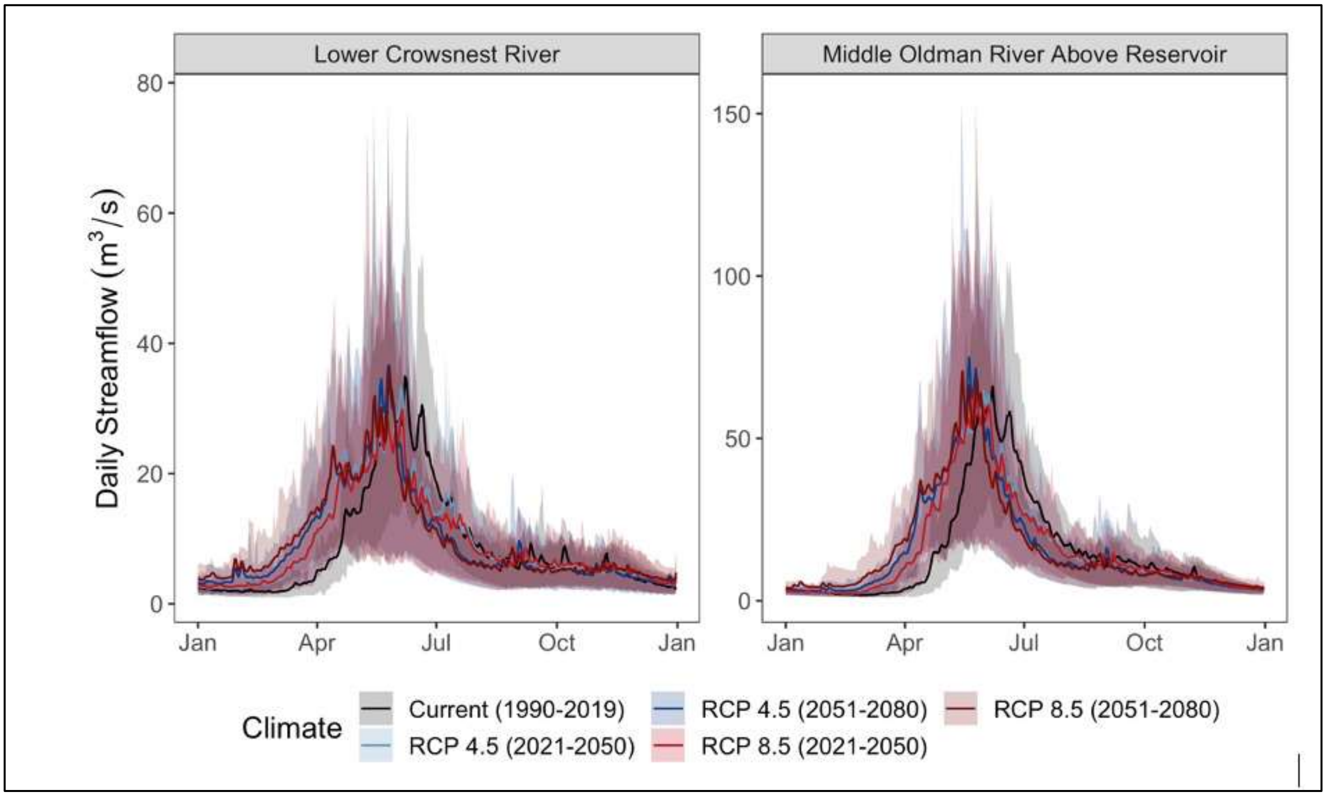


Figure 114. Daily streamflow for two major tributaries in the Oldman River under current conditions and future climate change scenarios. Solid lines correspond to the average while shaded areas correspond to 10-90% quantiles. Note that late summer flows decline markedly as runoff shifts to earlier in the year.

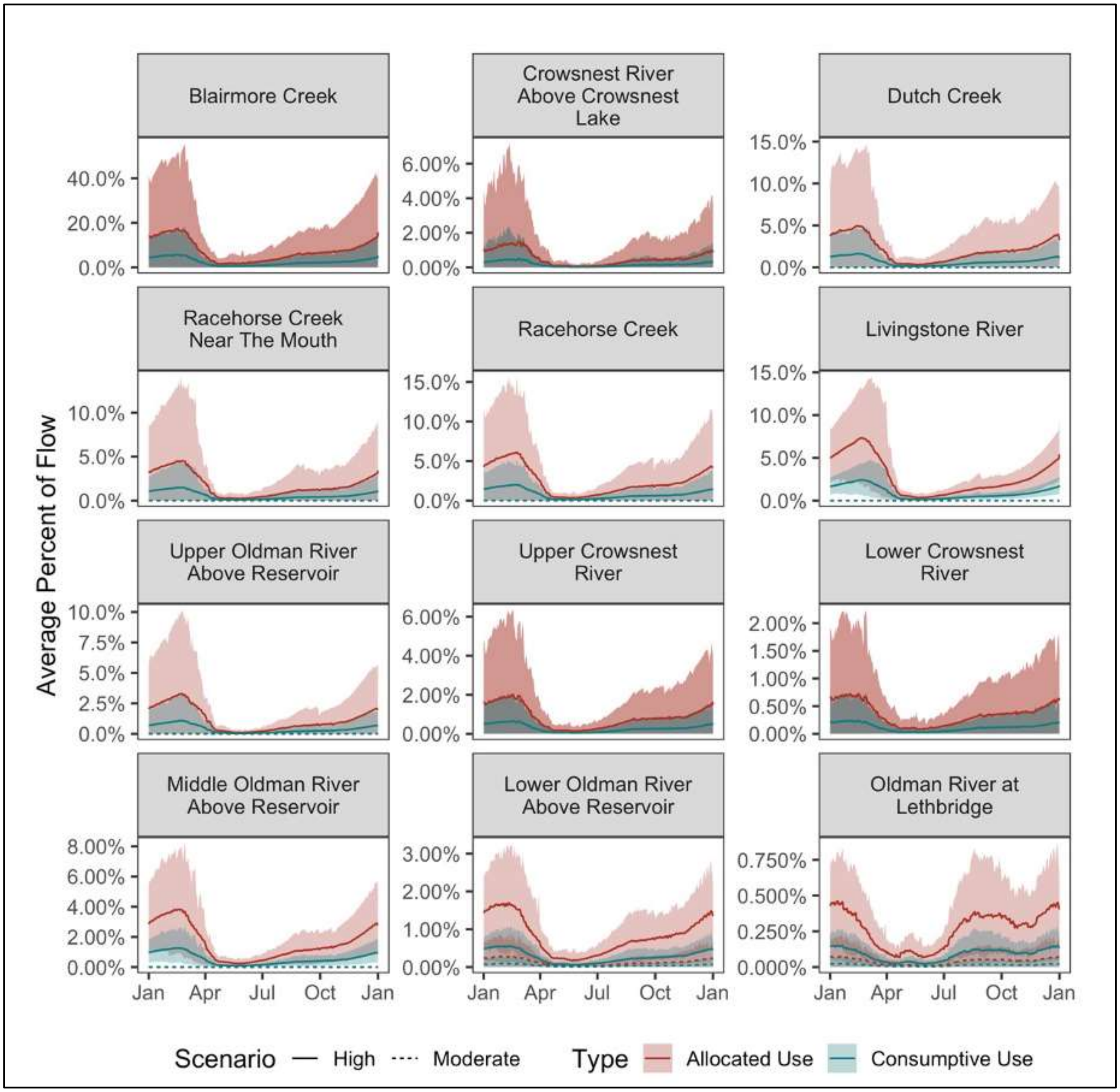


Figure 115. Percent of streamflow allocated and consumed under each mining scenario under the averaged future climate change projections. Solid lines represent the average over the 2025-2069 period while the shades lines represent the 10-90% quantiles (i.e. in four out of five years values are within this shaded area).

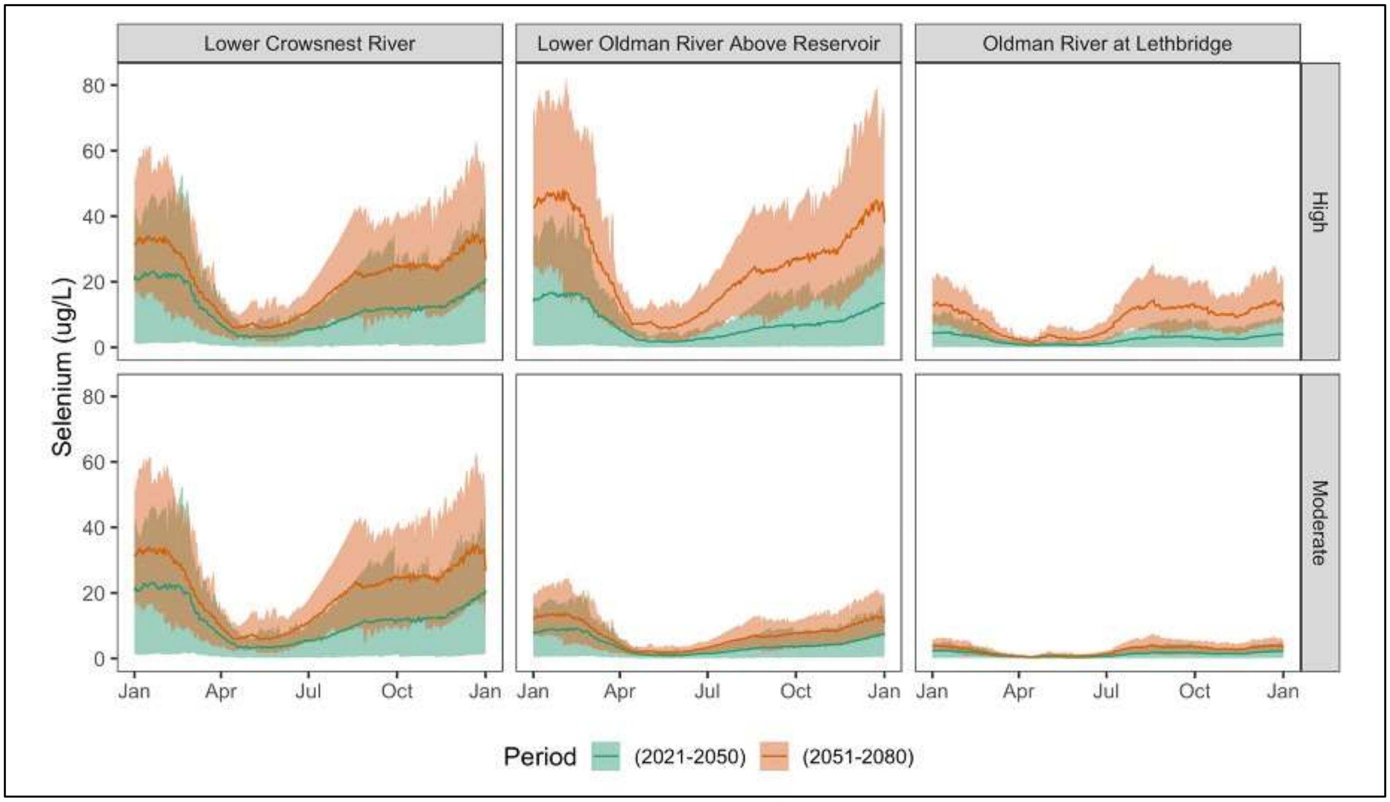


Figure 116. Average daily selenium concentrations at major river outlets assuming no attenuation under both mine development scenarios. Solid line corresponds to the average daily value while the shaded area corresponds to the 10 and 90% quantiles (i.e. four out of five years fall within the shaded area).

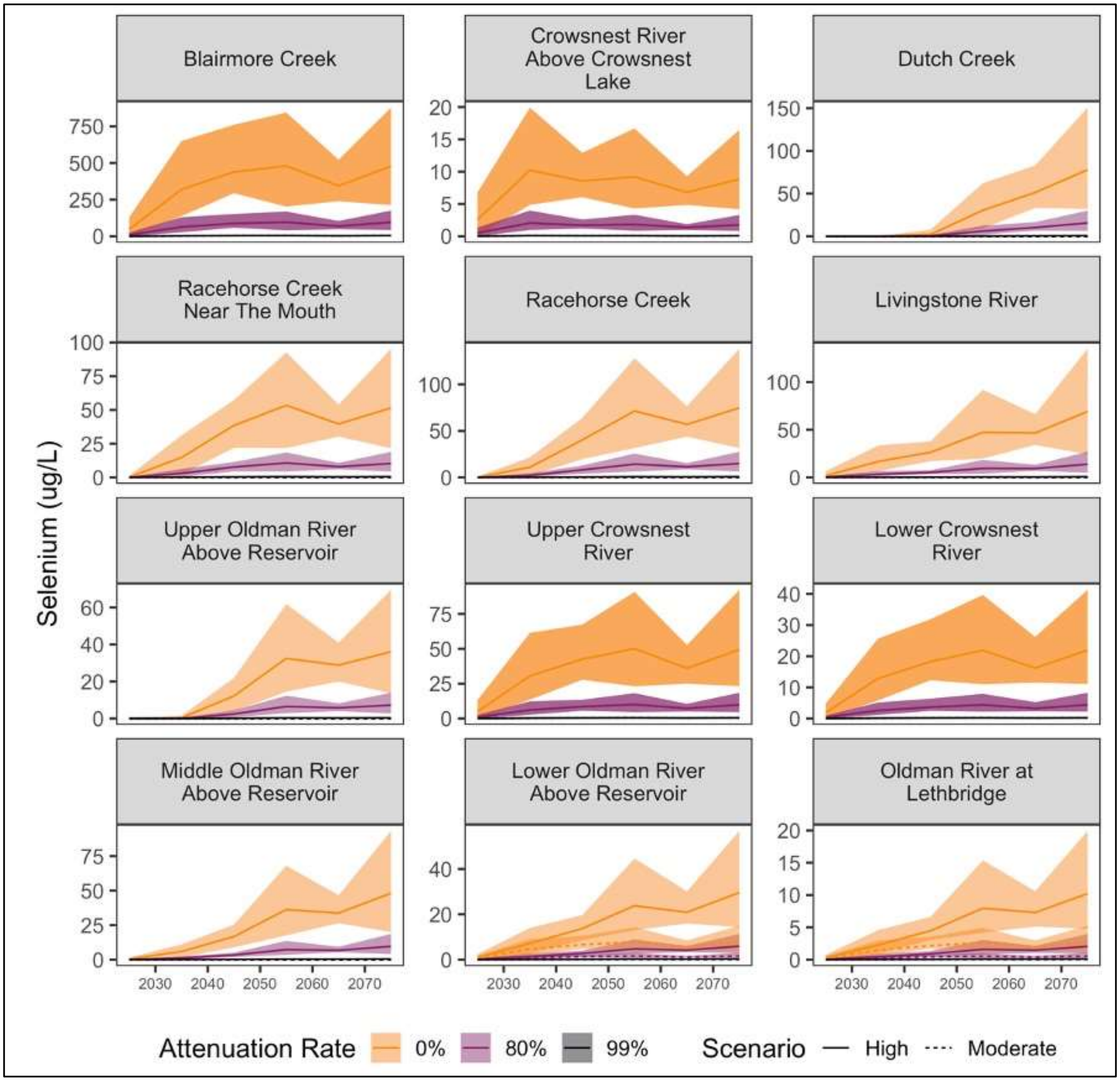


Figure 117. Average annual selenium concentrations at all affected sub-basin outlets under both mine development scenarios and three attenuation rates. Solid line corresponds to the decadal average value while the shaded area corresponds to the maximum and minimum annual averages for the decade.

Table 9. Minimum selenium attenuation rate required to meet various water quality guidelines at selected affected waterways in the Oldman River watershed under the High mine development scenario.

Site	Peak Annual Average Concentration (µg/L)	BC - Drinking Water	BC - Irrigation	Canada - Drinking Water	GoA - Aquatic Life	GoA - Irrigation (continuous)
Blairmore Creek	878	99%	99%	94%	100%	98%
Dutch Creek	151	93%	93%	67%	99%	87%
Racehorse Creek	138	93%	93%	64%	99%	86%
Livingstone River	135	93%	93%	63%	99%	85%
Racehorse Creek Near The Mouth	95	90%	90%	48%	98%	79%
Middle Oldman River Above Reservoir	93	89%	89%	46%	98%	79%
Upper Crowsnest River	92	89%	89%	46%	98%	78%
Upper Oldman River Above Reservoir	70	86%	86%	28%	97%	71%
Lower Oldman River Above Reservoir	57	82%	82%	12%	96%	65%
Lower Crowsnest River	41	76%	76%	0%	95%	52%
Crowsnest River Above Crowsnest Lake	20	50%	50%	0%	90%	0%
Oldman River at Lethbridge	20	50%	50%	0%	90%	0%

The Economics of Coal Mining

Economic arguments favouring coal mining emphasize its contributions to local employment and royalties paid to the Crown[171]. Those assessing the economic merits of coal mining should contrast the benefits against the equally real costs and liabilities associated with this industry. Minimally, these costs should include the following considerations:

- public reclamation costs should the private sector not be able to reclaim abandoned mines
- public cost for downstream water treatment[172]
- public cost for reclaiming fish habitat and degraded populations (an example would be Westslope cutthroat trout)[173]
- public cost for health care issues relating to air and water emissions from coal mining activities[174]
- public costs associated with adverse effects of climate change emissions from coal mining[175]
- losses in revenue to ecotourism, real estate, and recreation caused by a landscape dominated by ~120 km^2 of active coal mining footprint.[176]
- loss of market value to livestock sector and irrigated crops in southern Alberta if water quality and or quantity is compromised[177]
- social disruption costs associated with fluctuating coal commodity prices that are likely to translate to periodic lay-offs and re-hirings in the coal sector.

At the time of writing this report, detailed studies addressing the adverse effects of coal mining on the economic metrics listed above could not be found. It would seem prudent for the Government of Alberta, and its citizens, to know the answers to these questions before decisions are made concerning approval of future coal mines in the ORW headwaters.

As an example of this type of costs/benefit approach, the annual value of sport fishing in the Province of Alberta was estimated at $331 M in 1995[178] and $350 M in 2000 (Alberta, SRD). The angling opportunities provided by the ORW, which supports 31 fish species (Sport fish species of the Oldman River Watershed. Source: Oldman Watershed Council State of the Watershed Report (2015), is an important component of this provincial sport fishery. Numerous studies in Appalachia[179] and the nearby Elk Valley of BC have shown that extensive coal mining is associated with collapsed or threatened sport fish populations [180],[181]. What does the best available science tell us about projected loss in sport fish populations and their economic contributions, relative to the economic benefits (jobs, royalties) that will attend the regional development of coal mines in the headwaters of the ORW or throughout the East Slopes?

Recent analyses by Statistics Canada (2019)[182] computing the economic output of Alberta's tourism economy, highlight that the tourism sector annually supports 20,000 business, generates 68,000 jobs, attracts 34.7 million visits, and contributes $8.2 Billion (2019$; comprised of $3.9 B direct, $1.5 B indirect, and $1.1 B induced) to the provincial economy. A 2011 study examining the economic output of Kananaskis Country (adjacent to the northern boundary of the study area and similar in area and natural capital to the headwaters of the ORW), estimated annual economic value-added impact of ~$202.5 M/year (2011 $). It is widely understood that the East Slopes are a foundational component to our provincial tourism sector. If the tourism sector were to remain constant, it would contribute ~$400 B to Alberta's economy over the next 50 years. It seems prudent that the Government of Alberta, and Albertans, would want to know what loss in tourism-related economic output is likely to occur if significant portions of the East Slope headwaters are transformed into industrial landscapes dominated by coal mines.

The dominant land use in Alberta, in both area and economic contribution, is the agri-food sector (cattle, crops, irrigation, agro-processing). This sector employs about 77,000 Albertans and contributes $9.2 Billion to Alberta's provincial economy each year. Assuming that this sector does not grow or decline, it would contribute about $450 Billion in 2021 dollars to the provincial economy over the 50 year simulation period in this study. This sector is heavily dependent on adequate quality and quantity of water, of which most originates in Alberta's East Slopes.

No studies could be found that empirically examine the potential economic risks of an impending "full build out" East Slopes coal sector to the economic and social viability of tourism, agricultural, or other landuses. Without such information, no government is in a position to assess the consequences of a coal mining trajectory of such large spatial and temporal extent.

Conclusions

Local Watershed Consequences

Our simulations indicate the potential for significant, adverse, and long-lasting local environmental effects for all eight proposed coal mines. At the local scale of the mines themselves, development will cause the removal of all/nearly all vegetation, streams, and fish and wildlife habitat within the disturbance footprints, and alter surface and subsurface hydrology for a period of at least 20 to 35 years. Topography following mining will be different than pre-mine conditions, with higher elevations reduced and lower portions elevated. The total amount of rock and coal displaced is estimated at 1.11 and 6.71 km^3 (cubic kilometers) in the medium and high growth scenarios, respectively. Thereafter the period of structural disruption to local plant communities and hydrology will depend on the schedule and success of reclamation efforts. By the end of the 50 year simulation, the extent of reclamation is unlikely to exceed 25% of the total cumulative industrial footprint area. Important native grass species (especially fescue species) will be lost or greatly reduced from these areas as there is no known technology to re-establish high-elevation native fescue ecosystems on post-mined landscapes in a cost-effective manner.

For each tonne of coal produced, water use has been estimated at ~0.204 (gross) and 0.067 (net) m^3. As such, ~2/3 of the water extracted for coal mining and processing is scheduled to be released back into surface water flow. In the medium coal scenario, this will equate to gross water consumption of 1.2 M m^3/yr (at peak production), whereas the high coal scenario will consume gross volumes of ~4.9 M m^3/year. In all likelihood, water volume for coal mining will be sourced from local streams and/or groundwater. In the headwater systems, such as Blairmore Creek downstream of Grassy Mountain, allocated use of water could exceed 40% of flow during the late summer and early winter months during years of low precipitation. Similarly high rates of allocated water use by coal mines (exceeding 10% of flow) are expected to occur in Dutch Creek, Livingstone River, and Racehorse Creek during low flow months, and particularly during years with low precipitation.

For each m^3 of waste rock produced through coal mining, average selenium production from the oxidation of pyrite in waste rock could range from an estimated 0.55-3.2 mg/year. In the medium coal scenario, this could equate to a maximum annual peak production of 2.8 M g of selenium/yr, whereas the high coal scenario could yield 7.8 – 12 M g/year. Actual generation and subsequent release (load) of selenium into surface and subsurface water will depend on how effective the mitigation technologies deployed by coal companies are in attenuating selenium production and/or release. Using a range of potential attenuation efficiencies (from 99 to 50%), we expect that Se loading into water will vary between 7 to 700 mg/tonne of clean coal (during production), which could generate local dissolved concentrations between 1.5 and 500 µg/L immediately downstream of coal mines. (Concentrations > 1.0 µg/L exceed the alert level for protection of aquatic life.) Concentrations are expected to decline further downstream as dissolved selenium is diluted by additional water volumes from sub-catchments not affected by coal mining. Selenium loading from coal mining will lead to higher dissolved concentrations of selenium in all water downstream of the coal mines. Our results suggest that, with no mitigation, selenium concentrations would frequently exceed regulatory guidelines for both environmental and human health considerations, with exceedances being exacerbated during drier years when streamflow is lower and its ability to dilute selenium loading is reduced. Effective mitigation of selenium generation and release (i.e., attenuation rates of 90 to >99%) has the potential to retain selenium concentrations below water-quality thresholds. Therefore our results underscore the magnitude of the risk from under-performance of selenium-mitigation approaches, and highlights the importance of verifying that these approaches can actually achieve water-quality objectives.

The direct footprint (mine pit, waste-rock dumps, access roads, coal cleaning facilities, exploration drilling, conveyor system, coal load out, settling ponds) associated with coal mining will reduce both area and connectivity of streams and associated riparian habitat in the headwaters of the ORW. This is an important loss to local ecosystem function, as the ORW headwaters perform an important role as movement corridors for threatened species such Westslope cutthroat trout (WSCT).

At the scale of the mine site, the adverse effects on WSCT and aquatic invertebrates could be significant and persistent, reflecting complete loss of effective habitat for these taxa during the active lifespan of the mine, and for several decades after mines stop producing coal. Even if rudimentary stream systems are physically re-

constructed on the reclaimed mine sites, selenium concentrations could impair reproductive performance and cause physical deformities of WSCT in a manner similar to that observed in the Elk Valley to the west if selenium mitigation approaches are ineffective.

Although it is reasonable to believe that coal mines can re-establish vegetated ecosystems on graded, post-mined landscapes, there is no evidence that current reclamation practices can re-construct the spatial/temporal variance in ecosystem dynamics (water flow, water chemistry, plant community dynamics) that occur on the pre-mine landscape. Current constraints of knowledge, budget, and time prevent mining companies from returning these mined landscape to ones whose natural capital and ecosystem dynamics reflect pre-mining conditions.

Over the 50 year simulation, our simulations indicate that medium and high coal scenarios will produce the following average annual rates: clean coal (106.9, 693.8 M tonne) and CO_2e emissions (full life cycle; (293.4, 1,907.9 M tonne)). Over the simulation period, the estimated cumulative reclamation liability for medium and high coal scenarios would sum to $161 M and $938 M (2021 C$), respectively. At the end of 50 years, we estimate that only 25% of the mine will be reclaimed, and as such 75% of the cumulative liability would remain.

Regional Watershed Consequences

Models indicate that there could be significant regional-scale environmental effects for both medium and high coal mining scenarios, with effects being more pronounced for water quality than for water quantity, if mitigation approaches are less effective than claimed by environmental impact assessments. As a fraction of the total ORW water yield, the amount of water used for coal mining is comparatively small (<1%), with the fraction being much higher (frequently exceeding 10%) in headwater streams, late winter to early winter months, and during low-precipitation years. The total gross amount of water demand for coal 4.9 M m^3/yr; high scenario) is low compared to the irrigation sector, but will be 27% of the total gross water used by ORW's entire 1.1 M cattle population (18 M m^3/yr).

In general in oxic aquatic systems selenium is highly conserved and will not be removed in features like the Oldman River reservoir. Selenium concentrations will be reduced to the extent that additional non-affected waters dilute its concentration. Selenium concentrations in mainstem ORW rivers (and their tributaries with upstream coal mines) are projected to exceed water-quality guidelines for aquatic life, irrigation, and human drinking water during periods of low precipitation and streamflow with low to moderate attenuation of selenium release at the mine sources. The extent to which elevated selenium affects the health of humans, and the economic viability of the irrigation, livestock, and agro-food sectors, is a topic of immense concern but beyond the scope of this project.

The ORW is classified by the Government of Alberta as a closed basin in terms of water allocation[183]. In comparison to its maximum allocation volume (2.231 B m^3/yr), current use is 0.900 B m^3/yr. Our results indicate that while "average" water supply is currently adequate to meet water demand (use), continued growth of water demand (municipal, irrigation, livestock) coupled with "expected" drought events (templated from historical data) are likely to lead to conditions of water scarcity. Attempts to direct additional volumes of water to mining during drought conditions similar to those experienced in the past will likely violate the ICO thresholds and jeopardize the integrity of aquatic ecosystems of mainstem rivers and their tributaries.

Beyond the issues described above is the important consideration of future climate change. The drought events (frequency, magnitude) explored in this report were templated on historical data. Assuming that climate change dynamics continue to worsen, it is also likely that the frequency and magnitude of droughts in the ORW will be more problematic than we have presented. In such conditions, our simulations are likely under-estimating the magnitude of water scarcity issues in the ORW.

Recommendations

It is the recommendation of this report that coal mining in the headwaters of the ORW should not proceed until robust answers to critical questions are provided and discussed broadly by a diverse stakeholder community. The best available information indicates that the magnitude of long-term liabilities to water resources (quality,

quantity) are likely to exceed any short-term economic benefits. There is the risk that local adverse effects to water quantity (flow) and quality (selenium toxicity), streams, riparian habitat, and natural plant communities will be profound. Regional effects include a high likelihood of selenium concentration above threshold values throughout the ORW during years of low precipitation, particularly in late summer to early winter, if mitigation technologies underperform. Our analyses suggest that reasonable reclamation efforts would exceed a cumulative cost of ~$0.94 Billion (9,400 ha @ $100,000/ha; high scenario), with the possibility of much higher costs than that, and that ~75% of the disturbed area would remain unreclaimed at the end of the 50 year simulation. There is uncertainty that the Government of Alberta has implemented a bonding program that ensures adequate dollars are secured to fund appropriate reclamation practices.

There exists a diversity of land uses in the ORW, particularly the lower reaches, that are economically dependent on large quantities of high quality water. These land uses (including residential, crops, livestock, recreation, processing sectors), which currently generate several billion dollars annually as GDP, receive their water supply from the headwater basins of the ORW. The development of a coal sector in the headwaters of the ORW represents a real risk to these existing economic engines, and the families who depend on them.

Glossary and Acronyms

~	Approximately
AEP	Alberta Environment and Parks
AER	Alberta Energy Regulator
ALCES	A Landscape Cumulative Effects Simulator
ALSA	Alberta Land Stewardship Act
ALUF	Alberta Land Use Framework
AO	Alces Online
ARD	(Alberta) Agriculture and Rural Development
AUM	Animal Unit Months
BCM	Bank cubic meters
BMP	Best Management Practice
BRBC	Bow River Basin Council
BROM	Bow River Operational Model
BROM	Bow River Operational Model
BRP	Bow River Project
CAN	Computer-Aided Negotiation
CPAWS	Canadian Parks and Wilderness Society
CMT	Clean Metric Tonne
EID	Eastern Irrigation District
ESRD	(Alberta) Environment and Sustainable Resource Development
ESRD (Alberta)	Environment and Sustainable Resource Development
FLUZ	Forest Land Use Zone
FMU	Forest Management Units
FTE	Full Time Employee
FLUZ	Forest Land Use Zone
GHG	Greenhouse Gas
GoA	Government of Alberta
IDM	Irrigation Demand Model
IEG	Integrated Ecology Group
ICO	Instream Conservation Objectives
IJC	International Joint Commission
IO	Instream Objective
LLG	Livingstone Landowners Group
NDP	National Democratic Party
OHV	Off-highway vehicle
ORW	Oldman River Watershed
ORW	Oldman River Watershed
OSSK	Oldman and South Saskatchewan
OSSK	Oldman and South Saskatchewan (sub-basin)
OSSROM	Oldman and South Saskatchewan River Operational Model
PARC	Prairie Adaptation Research Collaborative
PM	Performance Measure
ROM	Run-of-Mine (raw coal straight from the mine)
SAR	Sodium Absorption Ratio
Se	Selenium
SMRID	St Mary River Irrigation District
SSRB	South Saskatchewan River Basin
SSROM	South Saskatchewan River Operational Model
UCP	United Conservative Party
UL	Tolerable Upper Intake Level

WCO	Water Conservation Objective
WHO	Health Organization
WID	Western Irrigation District
WID	Western Irrigation District
WPAC	Watershed Planning and Advisory Council
WPAC	Watershed Planning and Advisory Council
WRMM	Water Resources Management Model
WSCT	Westslope cutthroat trout
WSRP	Water Shortage Response Plan
ww	Wet weight basis

Units

BCM	Bank cubic meters
$C0_2e$	Carbon dioxide equivalent
cfs	cubic feet per second
CMT	clean metric tonne
dam^3	cubic decametre (1,000 cubic metres or 0.81 of an acre foot)
g	gram
kg	kilograms
km/km^2	km per square kilometer
L (or l)	Liter
m^3	Cubic meter
m^3/s	cubic meters per second (also written as cms; 1 m^3/s = 35.3 cubic feet per second)
mg	milligrams
mg/kg	dosage of substance (mg) based on body weight (kg)
mg/kg-d	dosage of substance (mg) based on body weight (kg) per day
MTA	million tonnes per year
ppb	Parts per billion = micrograms per Liter = microgram per kilogram
ppm	Parts per million = milligrams per Liter = milligrams per kilogram
µg	microgram
µg /l	microgram per liter (= 1 part for million; 1 ppm)
mg/L	milligram per liter (= 1 part for billion; 1 ppb)

Conversions

<u>Area</u>
1 ha = 10,000 m^2
1 km^2 = 100 ha

<u>Mass</u>
1 tonne = 1000 kg
1000 g = 1 kg
1000 mg = 1 g
1000 milligrams = 1 microgram

<u>Volume</u>
1 dam = 1000 m^3
1000 liters = 1 m^3
1 billion m^{3} = 1 km^3

Appendices

Appendix A. Legacy Coal Mines in the ORW

Underground coal mines were numerous and distributed throughout Alberta's east slopes during the late 1800s and early decades of the 1900s[184]. Surface coal mines were much less common and did not emerge until the 1950s. Coal from underground and surface mines provided cooking and heating fuel for both pioneer homes and early commercial businesses. A partial list of these mines in the ORW were identified using the online Mine Mapper app of the Government of Alberta[185] (Table 2). The boundary of the disturbed areas of some of the larger legacy surface coal mines is shown below (Figure 18). Almost all of these mines ceased to exist with the arrival of other hydrocarbon (oil, gas) fuel sources and the emergence of a provincial rural electrical grid in the 1960s. Another key factor to the reduction of Alberta's surface and sub-surface mines in the ORW was the rapid expansion (starting in the late 1960s[186]), and market dominance, of large-scale surface coal mining in the Elk Valley of southeast British Columbia.

Given the focus of water quality (selenium pollution) in this project, it is important to have some appreciation for the location, lifespan, and volume production (both coal and overburden rock) of legacy coal mines in the ORW. These legacy mines, and their spoil piles, are likely to be contributing selenium to surface and subsurface waters in the ORW. Knowledge of these legacy mines can also inform discussions about optimal placement of water sampling locations and distinguishing proper reference sites.

Table 10. List of legacy coal mines in the Crowsnest Pass region. Source: Government of Alberta Mine Finder[187].

Coal Mine Number	Coal Mine Name	Owner	Coal Mine Type	Status	Mining Method
0204	McGillivray Creek	McGillivray Creek Coal & Coke Co. Ltd.	Underground	Abandoned	Room and Pillar
0396	Greenhill	West Canadian Collieries Ltd.	Underground	Abandoned	Room and Pillar
0396/6	Greenhill Boisjoli	West Canadian Collieries Ltd.	Underground	Abandoned	Room and Pillar
0064	Lille	West Canadian Collieries Ltd.	Underground	Abandoned	Room and Pillar
1745	Grassy Mountain	West Canadian Collieries Ltd.	Surface	Abandoned	Open Pit
1745	Grassy Mountain	West Canadian Collieries Ltd.	Surface	Abandoned	Open Pit
1745	Grassy Mountain	West Canadian Collieries Ltd.	Surface	Abandoned	Open Pit
1745	Grassy Mountain	West Canadian Collieries Ltd.	Surface	Abandoned	Open Pit
0396/5	Greenhill	West Canadian Collieries Ltd.	Surface	Abandoned	Open Pit
0396/3	Greenhill	West Canadian Collieries Ltd.	Surface	Abandoned	Open Pit
0193	Blairmore	West Canadian Collieries Ltd.	Underground	Abandoned	Room and Pillar
0802	Sunburst	Blairmore Coal Co. Ltd.	Underground	Abandoned	Room and Pillar
0040	Hillcrest	Hillcrest Collieries Ltd.	Underground	Abandoned	Room and Pillar
0087	Bellevue	West Canadian Collieries Ltd.	Underground	Abandoned	Room and Pillar
0133	Maple Leaf	Mohawk Bituminous Mines Ltd.	Underground	Abandoned	Room and Pillar
0126/2	Passburg No.2	Leitch Collieries Ltd.	Underground	Abandoned	Room and Pillar
1747	Vicary Creek	Coleman Collieries Ltd.	Underground	Abandoned	Room and Pillar
1747	Vicary Creek	Coleman Collieries Ltd.	Underground	Abandoned	Room and Pillar
0088	International	International Coal and Coke Co. Ltd.	Underground	Abandoned	Room and Pillar
1584	Adanac	West Canadian Collieries Ltd.	Underground	Abandoned	Room and Pillar
0133/1	Mohawk No.5	Hillcrest Mohawk Collieries Ltd.	Underground	Abandoned	Room and Pillar
1275	Byron Creek	Byron Creek Collieries Ltd.	Underground	Abandoned	Room and Pillar
0048	Frank	Franco-Canadian Collieries Ltd.	Underground	Abandoned	Room and Pillar
0087/3	Adanac No.3	West Canadian Collieries Ltd.	Surface	Abandoned	Stripping Pit
0087/1	Adanac No.1	West Canadian Collieries Ltd.	Surface	Abandoned	Stripping Pit
1695	Tent Mountain	Coal Valley Resources Inc.	Surface	Suspended	Open Pit
1695	Tent Mountain	Coal Valley Resources Inc.	Surface	Suspended	Open Pit
1695	Tent Mountain	Coal Valley Resources Inc.	Surface	Suspended	Open Pit
1695	Tent Mountain	Coal Valley Resources Inc.	Surface	Suspended	Open Pit
1764	Racehorse	Coleman Collieries Ltd.	Surface	Abandoned	Open Pit
1710	Racehorse	Carl and Louis Shultz	Surface	Abandoned	Stripping Pit
0199/1	Beaver Mines No.2	Western Coal and Coke Co. Ltd.	Underground	Abandoned	Room and Pillar
0199	Beaver Mines No.1	Beaver Mines Coal Co.	Underground	Abandoned	Room and Pillar
0330	Link	Link Coal Co.	Underground	Abandoned	Room and Pillar

Table 11. Selected legacy coal mines in the headwaters of the ORW.

Name	Type/Location	Start Year	End Year	Cumulative Production tonne
Surface Mines				
Tent Mountain Mine	Southwest of Coleman	1950	1979	7.68 MT
Grassy Mountain Mine	North of Coleman	1956	1962	0.38 MT
Adanac UG Mine	South of Crowsnest Pass	1942	1962	0.69 MT
Adanac Surface Mine	South of Crowsnest Pass	Unknown	Unknown	Unknown
Racehorse Creek	North of Crowsnest Pass	Unknown	Unknown	Unknown
Vicary Creek	Coleman Collieries	1957	1981	7.48 MT
Spoil Piles and Dumps				
Old Tipple Site	outskirts of Coleman			

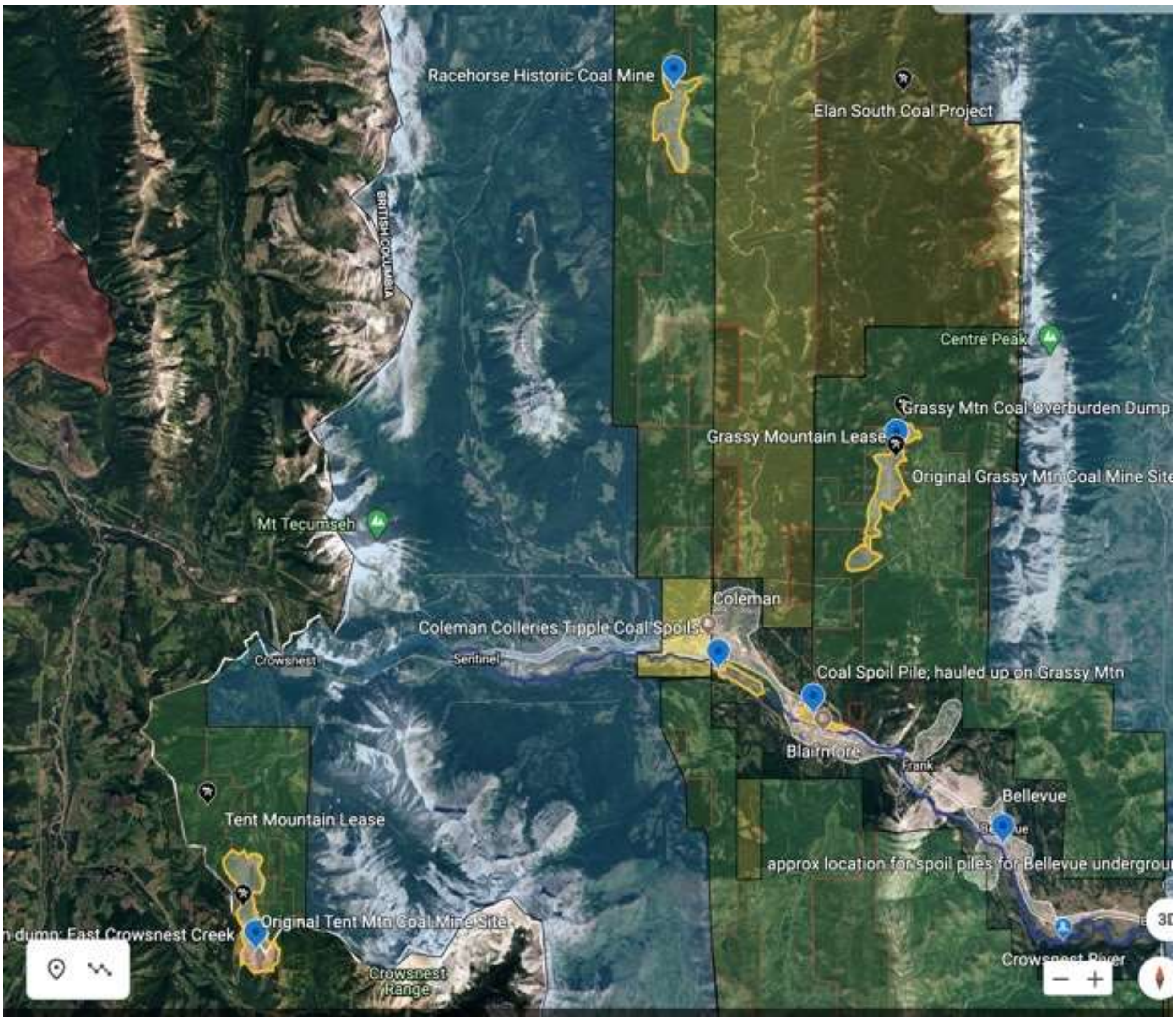


Figure 118. Approximate boundaries of surface legacy coal mines shown in yellow boundary.

Appendix B. Additional Details of Prospective Coal Mine Details

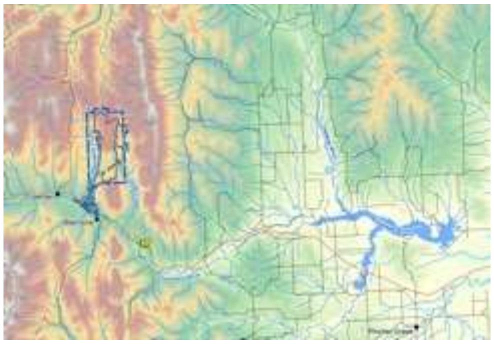
When selecting how best to simulate coal mining in the ORW, it was important to understand that the prospective coal mines were at different stages of investment or regulatory development. Some coal projects, such as Grassy Mtn and Tent Mtn, were proposals that extended earlier legacy mines operating under different regulatory requirements. The other projects (Elan South, Isolation South, Cabin Ridge, Isola, 4-Stack and Chinook) have acquired coal leases, have made formal applications for exploration to the Government of Alberta, and have published online prospectuses for investors. It is possible that some of these projects may chose not to go forward. It is also possible that other projects, which currently do not exist, will emerge and seek regulatory approval. As such, these scenarios do not represent a known certainty, but rather a plausible set of prospective coal mines given current knowledge.

This project has made every effort to adopt reasonable input assumptions for each of the "known" projects (coal production (MTA), lifespan, stripping ratio, location, reclamation trajectory, water requirement), based on either published metrics of the company itself, or where not available, using metrics relevant to Teck Resources operations immediately to the west.

Based on the literature review of the existing known coal mine projects, the cumulative coal production within the study area has been capped at ~700 MT over a 5-decade period. This volume is only produced during the High Production scenario. This value may prove to be somewhat low or high depending on future coal commodity prices, better coal reserve delineation, and whether the Government of Alberta choses to be more or less encouraging about coal development in the East Slopes. Given the uncertainty of these factors, we have adopted a sensitivity approach where we vary actual coal production from 0 MT (low), 5.875 MTA (only Grassy Mtn and Tent Mtn) and 23.95 MTA. Additional information on each coal mine project is provided in the next section.

Riverdale's Resources Grassy Mountain Coal Project

The Grassy Mountain Coal Project of Riversdale Resources[188] proposes to develop a 25-year, 4.5 MTA (million tonne per year) coking coal mine on Grassy Mountain immediately north of Coleman, Alberta. The location of the lease site in the ORW headwaters and our simulated mine activity boundary is provided in Figure 66. This proposal would re-open and expand the legacy Grassy Mountain coal mine, which ceased production ~1990. This new project would create a cumulative surface land disturbance of ~1,244 ha within their 83 km^2 lease. An oblique aerial image of the legacy coal mine footprint is shown below. The full spatial extent of the proposed coal mine, including open pit area, mine waste disposal area, backfill zone, plant, road and conveyor, surge pond, are provided below.



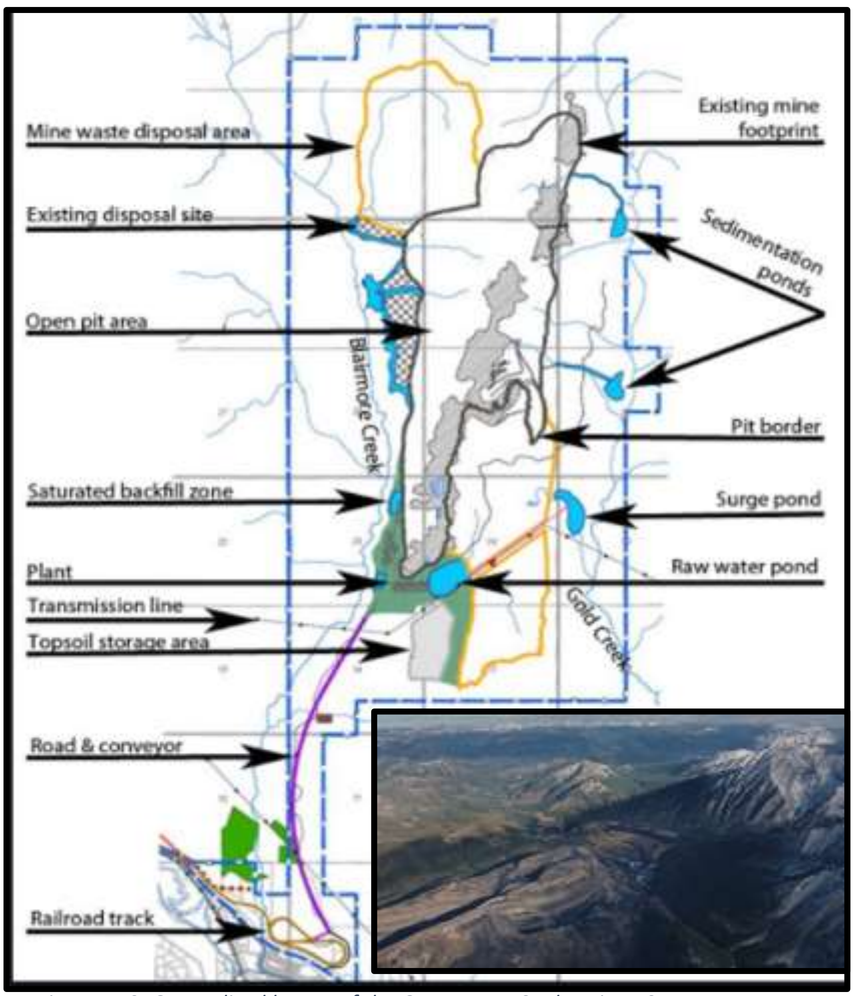


Figure 119. Generalized layout of the Grassy Mtn Coal Project. Source: http://www.rivresources.com/site/Projects/grassy-mountain-project2/overview3

Montem's Tent Mountain Coal Project

The Tent Mountain Coal Project of Montem Resources[189] proposes to develop a 14-year, 1.7 MTA (million tonne per year) coking coal mine on Tent Mountain on the AB/BC border southwest of Coleman, Alberta. The location of the lease site in the ORW headwaters and our simulated mine activity boundary is provided in Figure 66. This proposal would re-open and expand the legacy Tent Mountain coal mine, which ceased production in 1983. This new project would create a cumulative surface land disturbance of ~364 ha within their 19.3 km^2 lease. An oblique aerial image of the legacy coal mine footprint is shown below. The full spatial extent of the proposed coal mine, including open pit area, mine waste disposal area, backfill zone, plant, road and conveyor, surge pond, are provided below.

Figure 120. Generalized spatial layout of the proposed Tent Mountain Coal Mine Project. Source: https://montem-resources.com/projects/tent-mountain/

Atrum's Coal Projects (Isolation South and Elan South)

Atrum Coal Resources[190] hold a 230 km^2 tenement in southwest Alberta and has proposed to develop coal mines within their Elan North (Isolation South; 30 km^2) and Elan South (100 km^2) coal leases. The location of the lease site in the ORW headwaters and our simulated mine activity boundary is provided in Figure 66. Collectively, they have stated that these leases contain 298 Million tonne (70 MT Indicated, and 228 MT Inferred) of coking coal. For the Elan South project, Atrum suggests a 22-year mine that will produce an average of 4.5 MTA. For the Elan North (Isolation South) project, Atrum suggests a 35-year mine (called Isolation South) that will produce an average of 7.5 MTA. We estimate that this new project would create a cumulative surface land disturbance of ~2,550 ha within their 230 km^2 lease. The full spatial extent of the proposed coal mine, including associated infrastructure are provided below. The Savanna coal project lies in the Atrum North lease and contains 30 MT of total (measured and indicated) coking coal. Assuming this mine would produce at a rate of 2 MTA, the mine lifespan would be ~15 years. We are not including the Savanna coal project as part of this simulation project.

PROJECT	PROJECT AREA	MEASURED (Mt)	INDICATED (Mt)	MEASURED + INDICATED (Mt)	INFERRED (Mt)	TOTAL (Mt)	DATE REPORTED
ELAN NORTHERN TENEMENTS	ISOLATION SOUTH	7	168	175	88	262	25-Nov-20
	ISOLATION	-	-	-	51	51	22-Jan-19
	SAVANNA	-	-	-	30	30	22-Jan-19
ELAN SOUTH	SOUTH EAST CORNER	-	16	16	22	38	10-Feb-20
	FISH HOOK	-	15	15	11	26	10-Feb-20
	OIL PAD RIDGE	-	29	29	50	80	10-Feb-20
TOTAL		7	228	235	252	486	

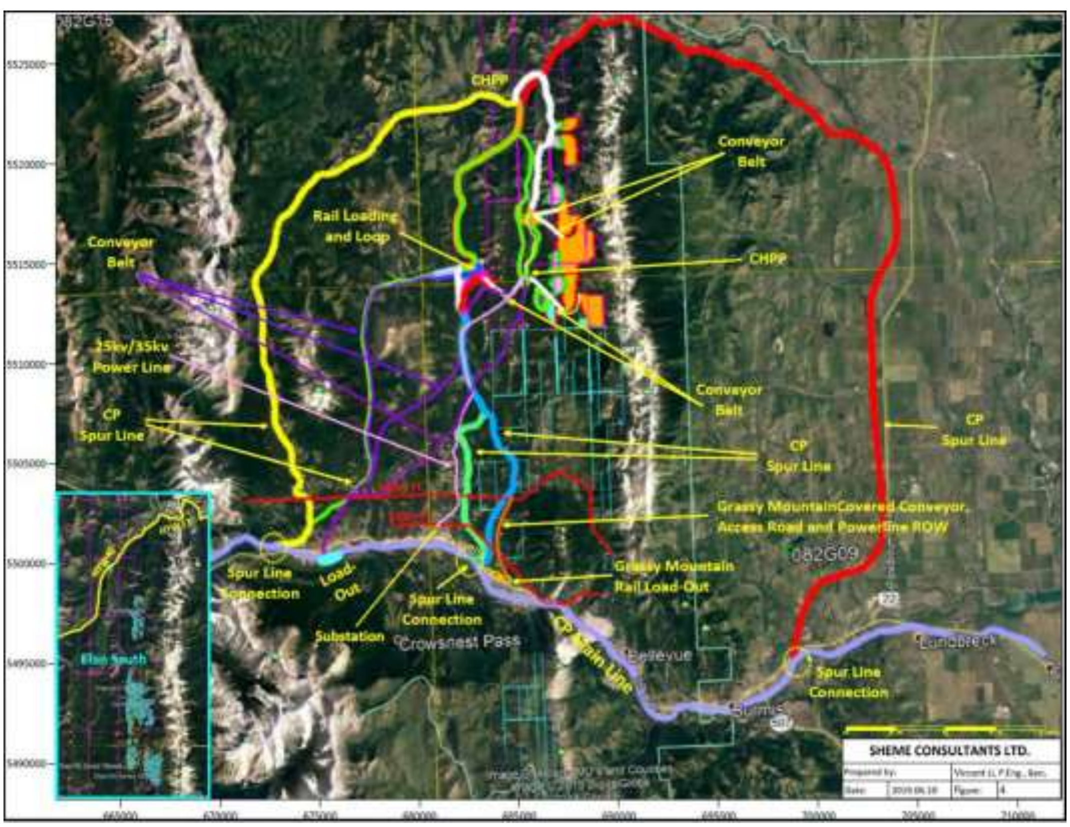
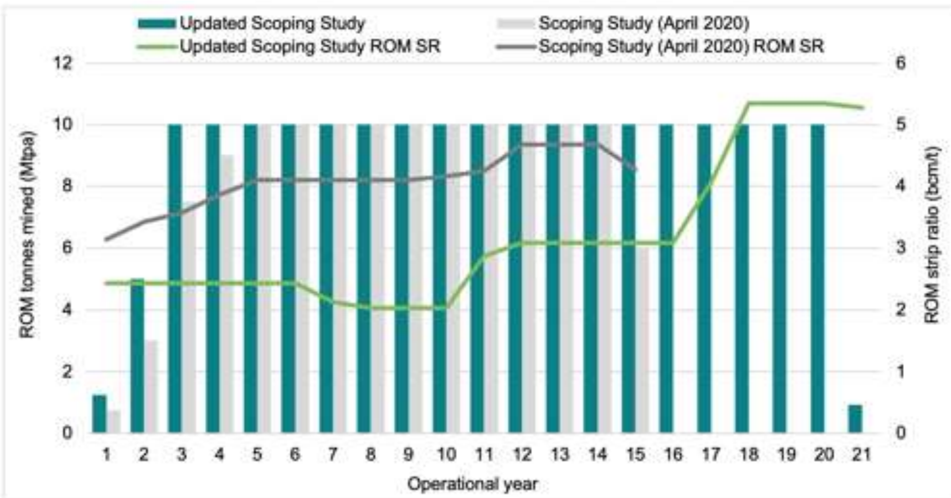


Figure 121. Location and proposed spatial layout of Atrum's South Elan coal projects. Source: https://www.atrumcoal.com/projects/elan-project/

Isolation South

The Isolation South Mine Project is located on Atrum's 6,239 ha lease. The location of the lease site in the ORW headwaters and our simulated mine activity boundary is provided in Figure 66. According to Atrum's online publications[191], this project identifies a proven coal resource of >112 MT and suggests a mine that could produce ~4.5 MTA for 21 years.



Inferred resources comprise only 14% of the overall mine schedule and an average of less than 10% over the first three years of operation. Atrum confirms that the financial viability of the Elan Project is not dependent on the inclusion of Inferred resources in the production schedule. The resource classification underpinning the life-of-mine schedule and production target in the Updated Scoping Study is outlined in Table 5.

Figure 122. Location and coal production trajectory for Atrum's Isolation south.

Montem Resources Northern Coal Projects (Isola, 4-Stack, Chinook)

Excluding their Tent Mountain holdings, Montem Resources[192] coal leases contain ~140 MT of measured, indicated, and/or inferred coking coal. The location of the lease site in the ORW headwaters and our simulated mine activity boundary is provided in Figure 66. On their ~116 km^2 lease, Montem has proposed to develop two coal mines (Chinook Vicary (100 km^2 lease), Chinook South[193]).

Isola

The Isola Coal Mine Project is located on Montem's 4,832 ha lease. The location of the lease site in the ORW headwaters and our simulated mine activity boundary is provided in Figure 66. According to Montem's online publications (), this project identifies a proven coal resource of >100 MT and suggests a mine that could produce ~4.5 MTA for 25 years.

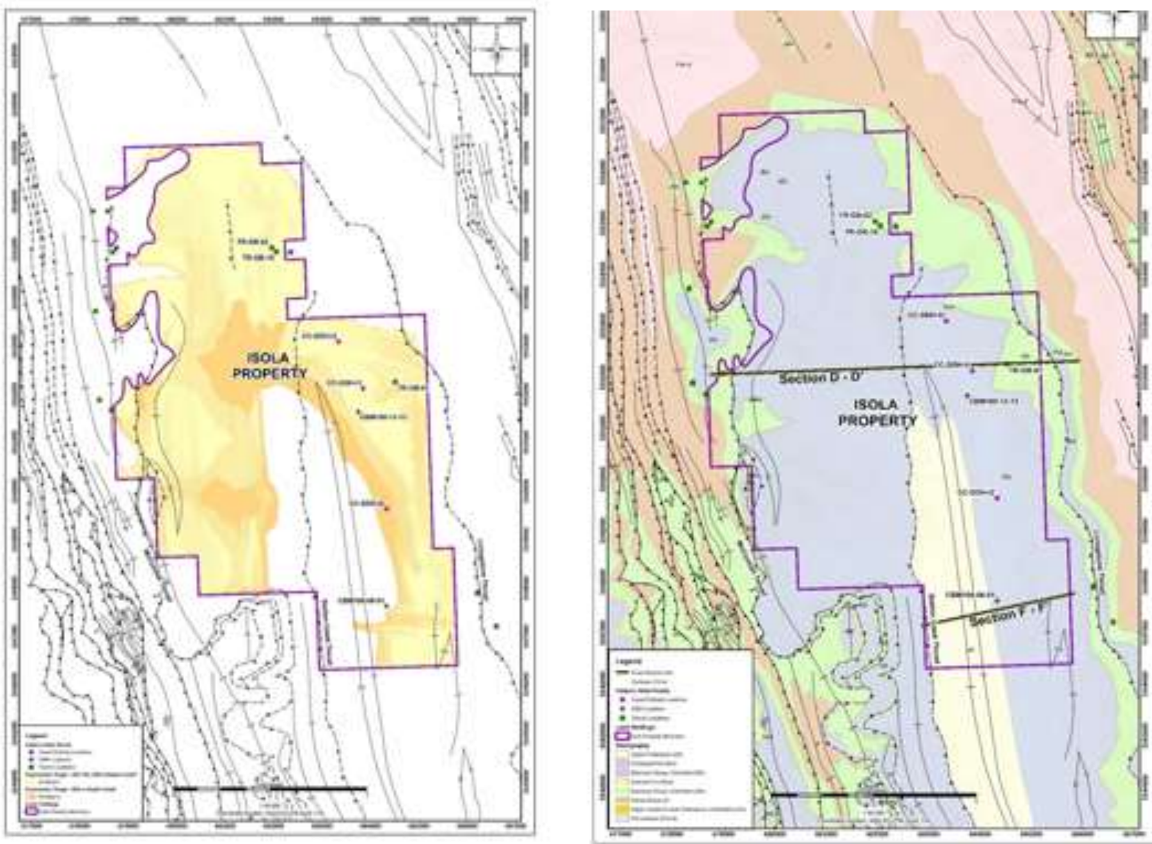


Figure 123. https://montem-resources.com/wp-content/uploads/2020/07/2020-07-05_Isola-Summary-Report_Final.pdf. This map is helpful in locating the likely mine site for Isola

Chinook – Vicary

The Chinook-Vicary Coal Mine Project is located on Montem's 10,000 ha lease. The location of the lease site in the ORW headwaters and our simulated mine activity boundary is provided in Figure 66. According to Montem's online publications (), this project identifies a proven coal resource of >149 MT and suggests a mine that could produce ~4.5 MTA for 25 years.

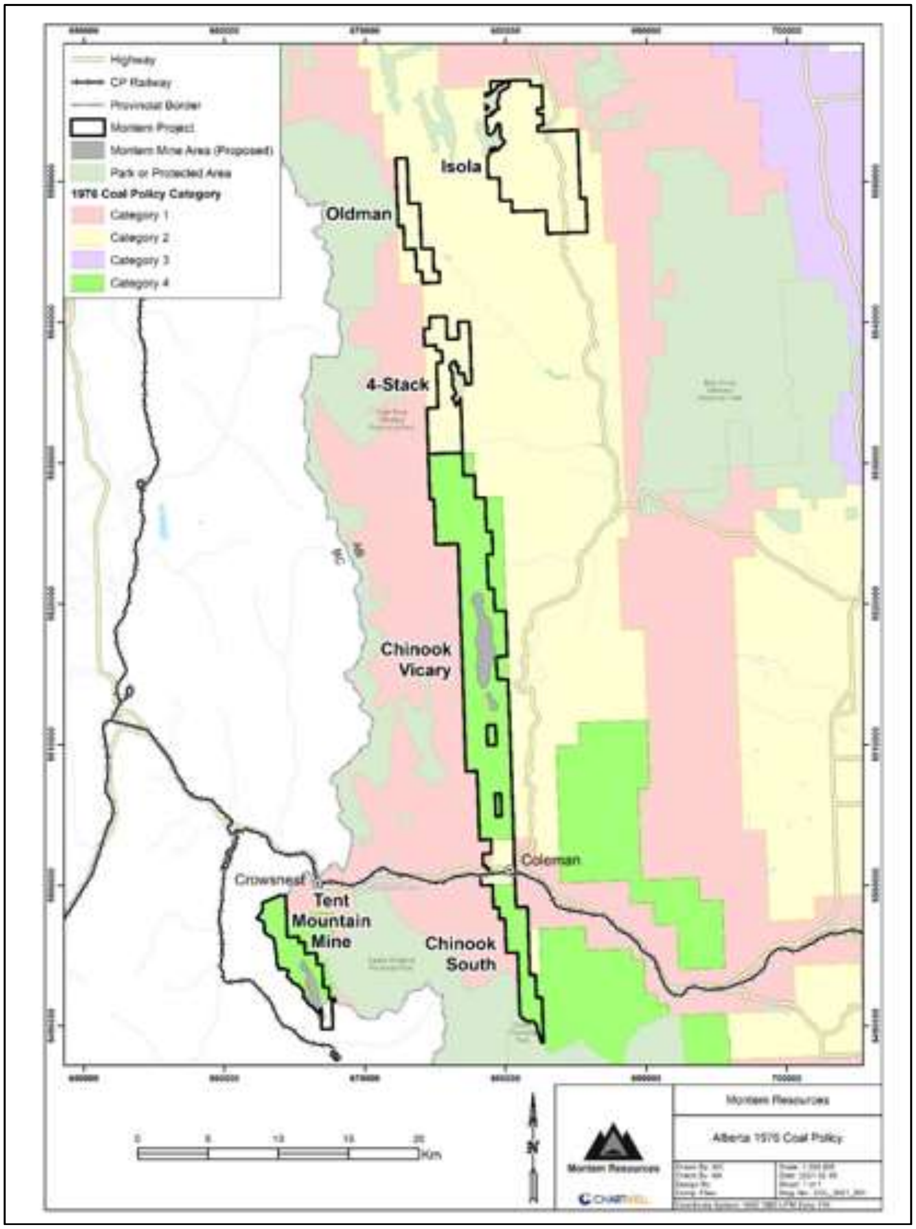


Figure 124. The likely location of the mine site for Chinook Vicary.

4-Stack

The 4-Stack Coal Mine Project is located on Montem's 1,965 ha lease. The location of the lease site in the ORW headwaters and our simulated mine activity boundary is provided in Figure 66. According to Montem's online publications, this project identifies a proven coal resource of >100 MT and suggests a mine that could produce ~4.5 MTA for 22 years.

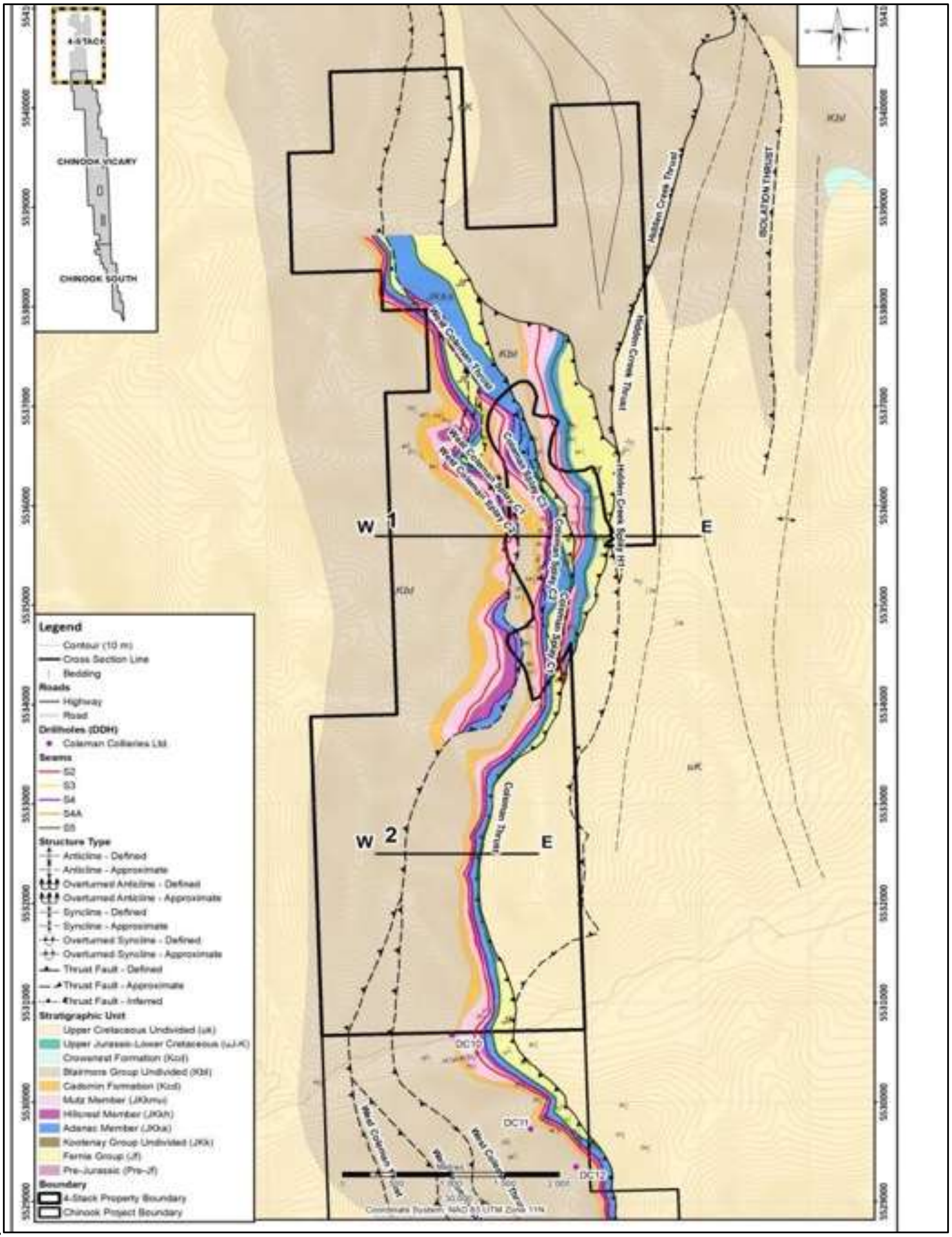


Figure 125. Shows 4 Stack coal mine project.

Warburton’s Cabin Ridge Coal Mine Project

The Cabin Ridge Coal Mine Project is located on Warburton’s 5,000 ha lease in the headwaters of the ORW (Figure 155). According to Warburton’s online publication, this project identifies proven coal resource of 100 MT and proposes a mine that produces ~4.5 MTA for 23 years. A significant area of surface disturbances relating to roads and drill-holes have been completed (Figure 156).

Figure 126. Location of Warburton’s Cabin Ridge Project.

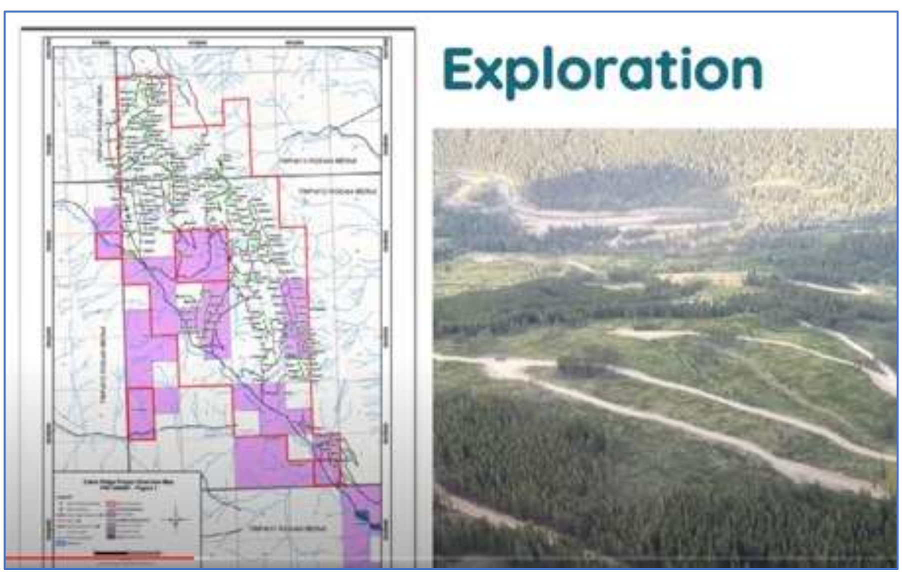


Figure 127. Recent exploration on Cabin Ridge. Source: Image extracted from CPAWS website.

Location of prospective active coal mining within leases.

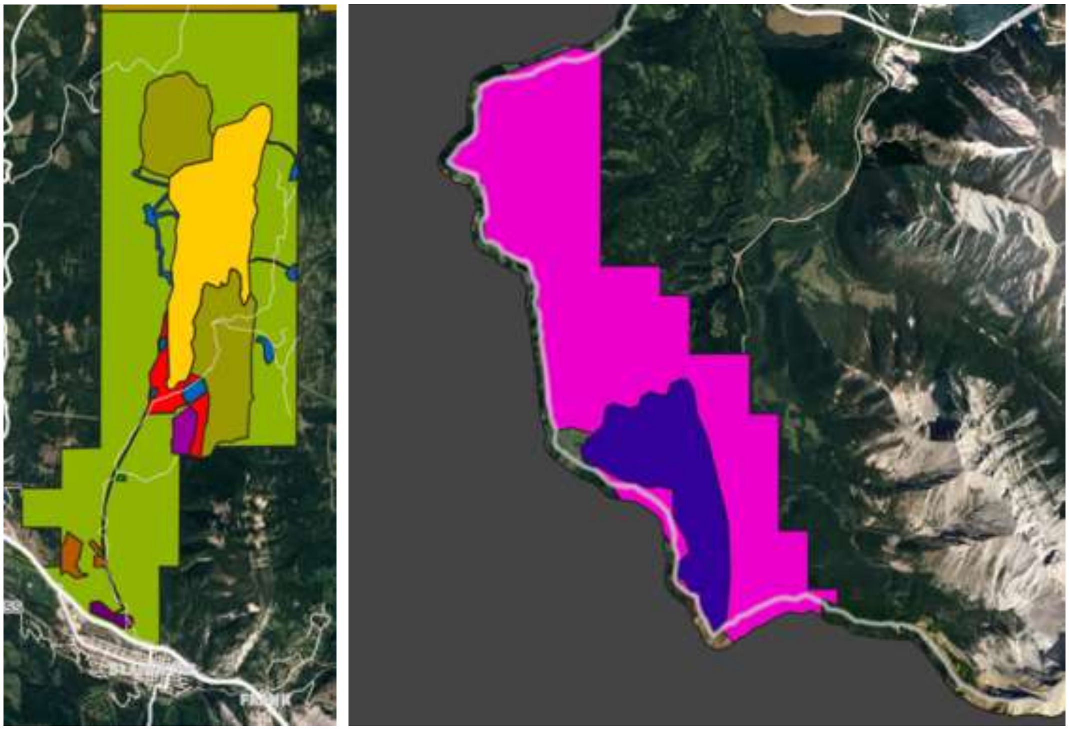


Figure 128. Boundaries of Grassy Mountain (left) and Tent Mountain (right) Coal project leases. Polygon within leases reflect simulated active mining disturbance sites.

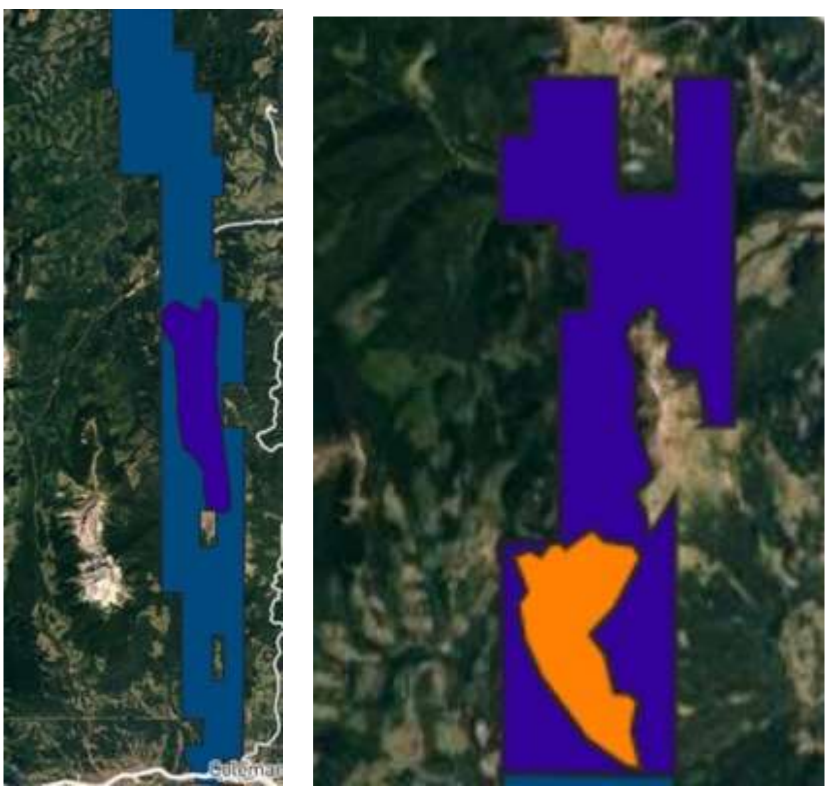


Figure 129. Boundaries of Chinook/Vicary (left) and 4-Stack coal project leases. Polygon within leases reflect simulated active mining disturbance sites.

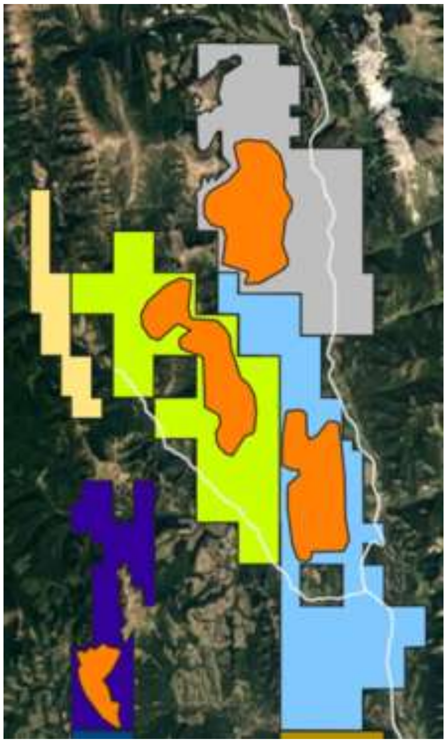


Figure 130. Boundaries of four different coal mines (orange) within the 4-Stack (purple), Isola (grey), Isolation South (light blue), and Cabin Ridge (green) project boundaries.

Appendix C. 1974 Environmental Conservation Authorities (ECA) Assessment of Coal Mining in Alberta's Eastern Slopes

"4.2.5.1 Coal
The coal which occurs in the foothills and mountains of Alberta is generally bituminous, though some anthracite is found. Some of the deposits make a good coking coal, and there is a market for this material as an export commodity in the manufacture of steel. New markets for anthracite coal as a thermal fuel are also appearing. The Authority has always been careful to distinguish the cost/benefit balance that production of coal in the plains may achieve in the province as against the cost/benefit balance that mining for coal in the foothills and mountains might show.

4.2.5.1.1 Coal Mining
The history of coal mining in mountainous countries, whether in Alberta or in other parts of the world, has unfortunately been unhappy throughout. In the Eastern Slopes of Alberta, it has its own case history, its own set of problems and advantages and disadvantages. In the Eastern Slopes, surface mining for coal is in conflict with virtually every other use to which the Slopes might be put. Tourism, recreation, fish and wildlife, watershed protection, the preservation of natural areas and sites, indeed even the maintenance of stable communities, all have long histories of incompatibility with coal mining, whether it be surface or underground, in the Eastern Slopes. The difficulty has always been that these important disbenefits are not balanced by proportionate advantages.

In the Eastern Slopes coal is often mined by companies owned abroad. The major expenditure these companies make is for huge machinery that is also purchased abroad. Surface mines require a relatively small group of employees, and even this somewhat specialized labour pool is apt to be in short supply and is rather mobile, so that the number of Albertans who want this kind of work for the most part already have it. The royalty charge by the province on the coal, at ten cents a ton, is an insignificant source of revenue. The roads, the railroads, and the towns the operation of the mines may entail have generally been built either at government cost or with government subsidy. Yet at the present time all of the coal produced from the Eastern Slopes is, after only a rough washing, exported as a raw material to markets far from Canada. It therefore makes no contribution to industrial development in Alberta or in Canada.

The damage and devastation left behind in the process of surface mining from the coal washing plants on the sides of brooks and rivers which release coal fines that settle out on brooks and streams and smother the young trout fry, the dangerously dammed lagoons high in the mountains, the incredible devastation of the mountainside invoked by the giant machines, and the spoil and spill piles exposed to erosion on the steep slopes pouring down into the valleys and destroying the trees, the other vegetation, and the river beds, make it possible to wonder why this particular resource is exploited at all. Only one company has claimed that even under these conditions it has made a profit.

The risks of the export market, bad management in the mines including bad environmental management, poor bargaining done on behalf of the collieries so that contracts could not be met and money was lost even by the companies themselves, the list of coal mining towns that have become ghost towns or have fallen into decrepitude or are still permanently marred by the marks of the industry to the disadvantage of the present inhabitants, the clear insecurity of a community that relies on the export of coal markets alone, all indicated that the development of the coal mining resources in the Eastern Slopes should be approached with caution. That caution should only be removed to the extent that some of the disadvantages enumerated can be turned into advantages, or when in other ways it can be shown that coal mining produces greater benefits in the overall that other ways of using the Eastern Slopes.

Though only a relatively small percentage of the coal known to occur within the Eastern Slopes can be recovered through surface mining techniques, present plans emphasize this technique almost exclusively as against underground or other alternate ways. Though underground or alternate methods may have problems of their own, they certainly create less lurid devastation than does surface mining, at least while the mine is in operation. On the other hand, it may well be that permanent satisfactory reclamation will be easier to realize following surface mining, than following underground mining. This problem was dealt with in considerable detail in the earlier hearings of the Authority.

An alternate approach to the problem of recovering the coal resource is hydraulic mining. This method employs water under high pressure that cuts and sluices the coal out of the deposit, to be recovered from the slurry that is produced. The water is recycled, it is claimed, so that only make-up water needs to be added as the mining continues and no waste water is returned to surface drainage. The kinds of deposits that are amenable to hydraulic mining are limited, with a gravity flow for the slurry generally being one important requirement. This technology, which is being contemplated for Alberta, and which has been used in other countries, seems to hold some promise for coal extraction operations that may be less devastating and hence less in conflict with other uses of the land, than either surface mining or conventional underground mining. Much, however, remains to

be proven out about the several environmental impacts to be associated with hydraulic mining, before too much encouragement can be given to it.

Those areas of the world which have a long history of surface coal mining especially in the mountainous terrain have discovered serious problems in water quality deterioration. These quality changes are brought on by the leaching of minerals from subsurface material which had been brought to the surface but had never before been exposed to the run-off. In many cases, the change in quality made the water unsuitable for fish or even unsafe to drink. Within the Eastern Slopes, the reclamation process frequently exposes subsurface material to rainfall and run-off. There should be adequate protection to ensure that dissolved minerals do not destroy water quality.

The province in endowed with large coal resources distributed extensively throughout much of the Eastern Slopes. The Authority views these resources as an immediate source of potential wealth but whose rate of appreciation is deserving of careful consideration. It is unfortunate that the common practice has arisen of referring to coal, petroleum, and similar deposits as "fossil fuels" or "energy reserves" as it tends to relegate them to this rather low-grade application as their primary use. In fact, the chemical composition of these materials contains the molecular building blocks which technology converts into a variety of products which would sustain heavy chemical industries. They therefore have now, and will have to an increasing extent in the future, far more valuable applications for the benefit of mankind than merely being burnt for the fuel value, although even their value as a thermal fuel or as a coking agent is rapidly appreciating. Accordingly, a system of identifying and holding in reserve some of these resources would provide for orderly extraction and assurance of future supplies in the public benefit and in the support of long-term provincially based industries.

The world demand for resources is growing at an ever increasing pace. It is now evident that the rate of appreciation of the value of these resources should be again examined against any immediate economic benefits which may be gained. The province has within its resource vaults a huge store of raw materials whose value grows on a daily basis. It constitutes the birthright of future Albertans and therefore should not be squandered for limited economic gains today. A prudent system of resource planning requires that we assure the future as well as the present needs of our people through wise consumption and exploitation practices now.

RECOMMENDATIONS

(1) That surface mining be developed cautiously and in an orderly way both by careful site selection and by limiting the number of sites that can be worked at any one time, and the tonnage of coal or other material that can be extracted each year.
(2) That extractive development proceed in a fashion which demands total extraction and reclamation of one area before another is opened for development. This localizes disruption of the environment.
(3) That in all cases of mineral extraction through surface disturbance, but most particularly in such major disturbances as surface mining, fully integrated resource development, environmental management and surface reclamation programs be followed from the beginning.
(4) That known deposits of coal can now declared as future reserves and left undisturbed until required to service Alberta's needs.
(5) That such reserves reflect but not be limited to the environmental sensitivity of certain alpine and sub-alpine areas where the technology of reclamation has not been proven efficacious.
(6) That in a designated coal development zone the operations of all companies in exploration and extraction be so integrated and planned on a joint basis as to minimize surface disturbance and environmental damage and maximize the recovery of the coal in the deposit (See also Recommendation 2.)
(7) That, since reclamation and revegetation of sub-alpine surface mines is still experimental, the number and size of new mines be regulated, and expansion in the industry proceed cautiously, until reclamation technologies have proven their own efficacy.
(8) That particular attention be drawn to the Authority's previous recommendations that the Minister have discretion to hold safe from surface disturbance those areas of a high ecological sensitivity, and that a program to inventory such ecosensitive areas, and publish them, should be undertaken as soon as possible.
(9) That improved public acceptance of industrial and extractive developments in the Eastern Slopes be sought though greatly enhanced upgrading of inspection, publication of reclamation standards and regulations, increased enforcement activities and better public relations.
(10) That areas needing reclamation from previous surface and underground mining be so designated, and reclamation be undertaken with priority given to those basins in which watershed protection and watershed management are the more crucial.

(11) That non-renewable resource reserves be set aside, in which known non-renewable resources are to be kept in reserve and not released for development-based extraction except in a sequential way, perhaps at ten-year intervals, at a time still to be decided upon. (See also Recommendation 1, above.)
(12) That development work be undertaken to evaluate the efficacy of hydraulic mining for coal in the Eastern Slopes.
(13) That the administration of regulations and legislation related to the extraction of surface and sub-surface resources of the Eastern Slopes remain with the departments presently responsible. However, an expansion in field staff is recommended to ensure a more thorough inspection of conditions in the region and a stricter enforcement of land use legislation.
(14) That all streams and rivers be carefully monitored before surface mining commences to establish base line mineral contents.
(15) That mining proceed only under a set of conditions which prevents any change of the water quality due to dissolved minerals.
(16) That for additional and more detailed recommendations reference be made to the Authority's Report and Recommendations on the Impact on the Environment of Surface Mining in Alberta.

4.2.5.1.2 Coal Conservation
Surface mining "creams" the deposit and may leave much coal behind which is unprofitable to remove with existing techniques and under existing economic conditions. Later, extra costs must be incurred and new disturbances created or the resource may be lost to use indefinitely. This is a factor that is characteristic of coal mining in the Eastern Slopes.

An important problem therefore has to do with working out combinations of mining technologies that will achieve maximum utilization of the resource. The aim in all cases should be total recovery of the coal in the deposit rather than merely stripping the small portions that are economically lucrative at the time. This objective should be the basis of guidelines to be developed in respect of coal conservation in the Eastern Slopes.

RECOMMENDATION

(1) That the Energy Resources Conservation Board under is responsibilities in respect of coal conservation in the province and in co-operation with the coal companies investigate and propose technologies and combinations of technologies that will ensure the total, or failing that, the maximum possible exhaustion of the resource at any one site before that site is abandoned.

4.2.5.1.3 Exploration
Before a commercially viable coal mining operation can be established, complicated explorations must be conducted. These are normally carried out in two distinct and recognizably different phases which may be described as follows:

Phase 1. This earliest stage of exploration is aimed at determining and mapping the areas where coal deposits are most likely to be found, and may be done by some form of distant sensing such as airborne instrumentation or other device which causes little or no surface disturbance. Comparatively light surface operations including core drilling may then be performed to confirm the presence of the deposits and in a general way to determine the more promising locations for further exploration. Up to this point surface disturbances and the risk of environment damage are minimal.

Phase 2. It remains however, to determine where the deposits are of sufficient extent and are sufficiently favourably located with respect to the surface, to offer good commercial prospects. In this advanced phase, exploration proceeds by means of a series of exploratory trenchings supported by systematic borings to outline the deposit and enable a plan for mining it to be developed. These must, of necessity, be performed in situ, on the ground, and will usually cause considerable surface disturbances. Finally, what amounts to a small scale mining operation with all the attendant environmental damage, is carried out in the final exploratory operations where sample sizes of five hundred tons or more are extracted, processed, and shipped out to prospective customers for commercial evaluation. Surface access may also be required to the exploration site causing further damage and disturbance. It can thus be seen that the damage associated with mining in the foothills starts long before the actual commercial operation of the mine begins. In the course of trenching operations, vast areas of land, often virgin forest, are cleared in swaths 16 or more feet wide to make way for the trenching machines. These cuttings can follow or cut across the complex trails of the coal seams for miles across every kind of terrain, in many cases to be abandoned and repeated in new locations. When one realizes that all of this is happening in all kinds of weather, on slopes that are often quite steep and in some cases quite unstable, and that the heavy trenching equipment can become mired in mud and have to be rescued by equally heavy machines, it is difficult to discover an overall advantage from such activities in such fragile and beautiful terrain when the economic return to the province from the coal mining itself is so paltry. One cannot doubt that for the orderly development of Alberta's Eastern Slopes, a complete inventory of coal bearing areas would be a valuable asset. There is therefore a strong incentive to encourage the phase one type of exploration to achieve this. Further exploration in these areas should however only

be permitted after very careful consideration and under very closely controlled conditions. If one takes into account the inevitable appreciation in value that will occur as supplies of non-renewable resources such as coal become scarcer, as well as the reasonable expectation that more efficient and less environmentally hazardous exploratory devices and techniques will be developed in the future, there is a strong incentive to place a reserve on all coal in the foothills, and to take it out of reserve for phase two exploration and mining only when this can be done in better harmony with the environment.

Appendix D. 1984 Resource Management Policy for Alberta's Eastern Slopes

The government of Alberta received the advice of the 1974 Environmental Conservation Authority Eastern Slopes report. In 1984, the Government of Alberta released their own report (*A Policy for Resource Development of the Eastern Slopes of Alberta; Revised 1984*) that outlined their preferred policy direction. This document can be located online at: https://open.alberta.ca/publications/0864990677. The report re-enforces the critical role that the East Slopes performs for each of watershed function, wildlife habitat and populations, and aesthetics. This internal land-use integration exercise generated a map of the eastern slopes where all lands were allocated to one of several policy classifications that include: **protection** (prime protection, critical wildlife), **resource management** (special use, general recreation, multiple use, agriculture), and **development** (industrial, facility). In each of the 3 East Slope regions (southern, central, northern), the "multiple use" category contains the largest area (>75%), whereas protection classification comprised less than 10% of the total region. Based on input from relevant disciplines within government departments, the report defined (see below) and mapped (Figure 170) **prime protection** and **critical wildlife** zones, where industrial extractive activities should not occur. Based on recent government changes in coal policy, a significant amount of area within the 1984 "critical wildlife" category is now overlain with coal leases that have generated specific coal mining proposals (Figure 171). If coal mining is allowed to proceed in these regions, a significant reduction in areas considered critical to watershed and wildlife function will occur.

1. Prime Protection Zone

The intent of the prime protection zone is to preserve environmentally sensitive terrain and valuable ecological and aesthetic resources. It contains high-elevation forests and steep rocky slopes of the major mountain ranges in the Eastern Slopes. The lower boundary for this zone has been defined by elevation, ecological variables, and aesthetic qualities. The boundary generally represents the lower extremities of the more sensitive terrain in the Eastern Slopes.

This zone is intended to protect the rugged mountain scenery for which the region is highly valued. It is the zone which receives the greatest amounts of precipitation and produces most of the streamflow of the Eastern Slopes. Many critical wildlife ranges, especially for bighorn sheep and mountain goats, are found within this zone.

Regional objectives which are considered compatible with the intent of this zone include those of watershed, fisheries and wildlife management, and extensive recreational activities such as hunting, trail use (non-motorized) and primitive camping. The objective for commercial fur harvesting will also be met to some degree. Future access or utility corridors may be required through this zone. Approved snowmobile trails may also cross this zone. Future commercial ski development may be considered in this zone, as it contains the only suitable snow and terrain conditions in the Eastern Slopes. In these cases, the ski lifts and associated facilities will be permitted in the prime protection zone, while accommodation and other services will be located in adjacent zones where such commercial development is appropriate. Where considered essential and under strict operating guidelines, management programs may include activities such as wildlife habitat improvement, fire control and timber sanitation cutting to protect merchantable timber in other zones.

2. Critical Wildlife Zone

The Eastern Slopes is a unique and important wildlife region due to the many combinations of climate, topography and vegetation which provide habitat for a wide variety of species. The intent of the critical wildlife zone is to protect ranges or terrestrial and aquatic habitats that are crucial to the maintenance of specific fish and wildlife populations.

The zone consists of such areas as key winter range, migration routes and calving areas that are essential to the survival of specific wildlife species such as mountain goats, bighorn sheep, elk, and caribou, and of spawning areas vital to maintaining naturally reproducing salmonid populations. The zoning recognizes only those habitat areas which are crucial to the life cycle of particular species due to vegetation, climate, or topography. Regional objectives which are considered compatible with the intent of this zone include watershed, fisheries and wildlife management, serviced camping, and extensive recreation activities such as hunting and fishing, trail use and primitive camping. Resource extraction objectives such as those of trapping, logging, domestic grazing, petroleum,

natural gas, coal and mineral exploration and development may be achieved. Future roads or utility corridors may require access through this zone.

BROAD AREAS	INTENTS
Protection	To provide the highest level of protection for those areas which are known to form the unique character of the Eastern Slopes.
Resource Management	To foster wise mixed use of the natural resources to achieve specific goals and objectives.
Development	To recognize existing and provide for future site-specific development.

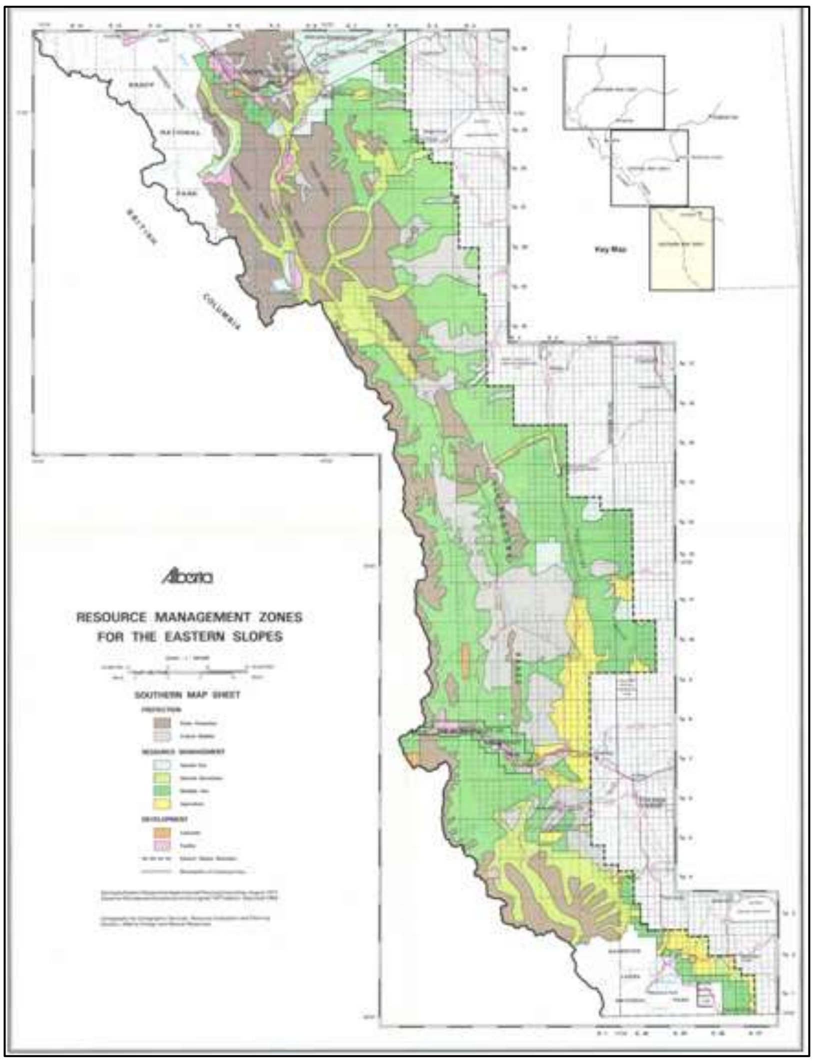


Figure 131. Map outlining the key land use priorities of the southern portion of the Eastern Slopes. Source: Government of Alberta. Resource Management Zones for the Eastern Slopes.

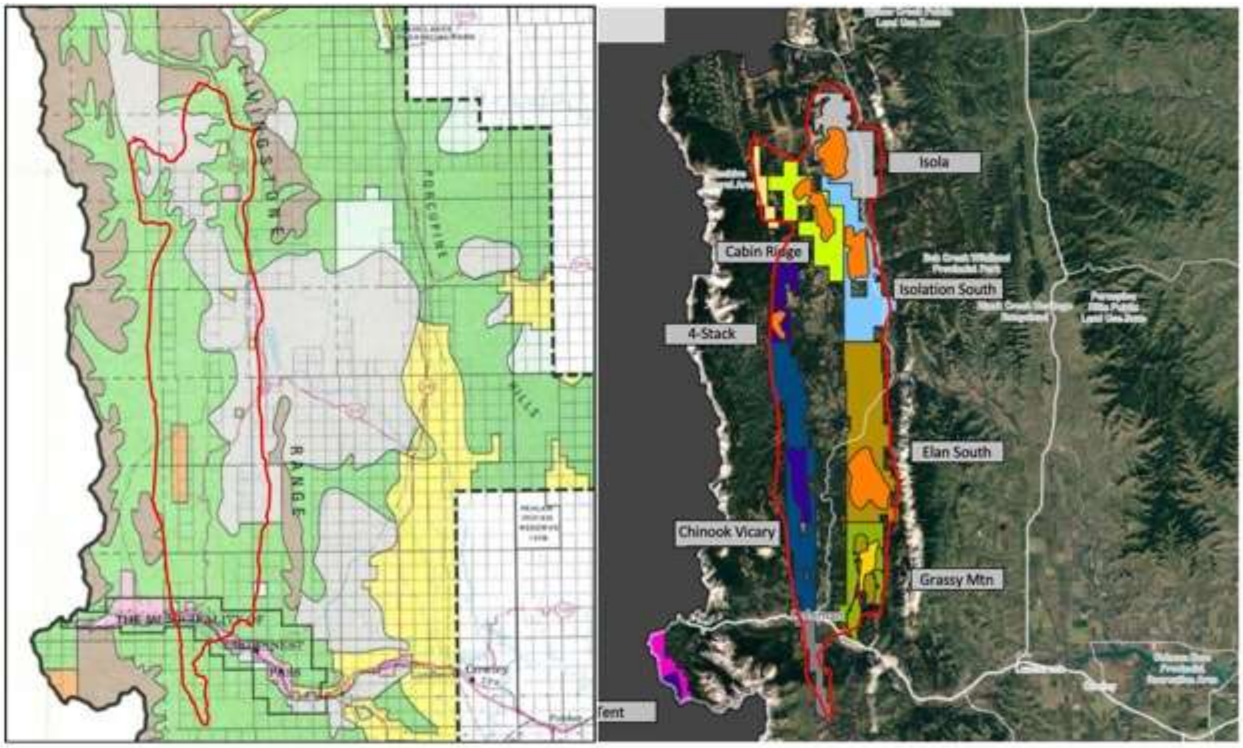


Figure 132. Comparison of the 1984 Government of Alberta East Slopes Policy map and current Coal Mining Leases. Note that the proposed coal leases overlap extensively with the grey polygons defined as critical wildlife habitat in the 1984 Resource Management Policy for Alberta's Eastern Slopes.

Appendix E. Additional Geology Information Concerning Coal Deposits

The information that follows was extracted from the report[194] entitled: Gorham, J. , Bradley Ulry, Matthew Carter, Nathan Schmidt. 2020. Coal resources for the Chinook project, Alberta, Canada. Prepared for Montem Resources, Alberta Operations Ltd. Competent Persons Report. Prepared by Dahrouge Geological Consulting, Edmonton, Alberta.

6 Geological Setting and Mineralization

6.1 Regional Geology

The Property lies within the Front Ranges of the Canadian Rocky Mountains, in southwestern Alberta, and spans the north-trending, west-dipping Coleman, Isolation and McConnell Thrust sheets. Stratigraphy on these thrust sheets is highly deformed due to complex folding and fault splays that displace strata up to 10 km (McDonald et al., 1989). The area is characterized by Precambrian to Upper Cretaceous rocks of the Fernie Group, Kootenay Group, Blairmore Group, and Crowsnest Formation, and undivided Upper Cretaceous formations (Figure 6-1 and Figure 6-2). Economic coal potential in the Front Ranges lies in the Mist Mountain Formation of the Kootenay Group, which is disconformably overlain by pebble conglomerates of the Cadomin Formation of the Blairmore Group. The Kootenay Group has a maximum thickness of 1,100 m near Sparwood, with an eastward thinning and grades into the Nikanassin Formation near the North Saskatchewan River (Stockmal et al., 2001).

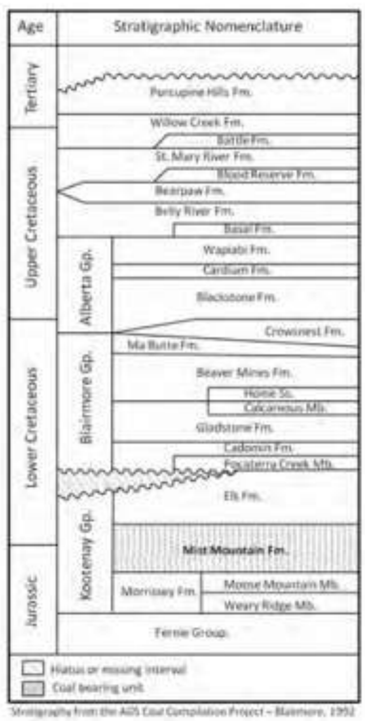


Figure 6-1 Stratigraphic Column (Modified from Richardson et al., 1992)

The oldest relevant unit in the area, the Jurassic Fernie Group, is comprised of dark-grey and black shales locally interbedded with phosphatic sandstones and limestones; cherty limestones, bedded siltstones,

sandstones and oolitic limestones; coquinas; concretionary bands; and glauconitic sandstones (Hall, 1984).

The Late Jurassic to Early Cretaceous Kootenay Group overlies the Fernie Group and is subdivided into three formations, the Morrissey, Mist Mountain and Elk Formations; however, in the Crowsnest Pass area, the Elk Formation is absent due to either erosion and/or thinning. Faulting and folding in the Crowsnest area make confirmation of the number of coal seams within the Kootenay Group difficult.

- The Morrissey Formation overlies the Jurassic Fernie Group and is subdivided into the basal Weary Ridge Member and the upper Moose Mountain Member. The Weary Ridge Member is comprised of a calcareous sandstone with minor interbedded siltstone and mudstone. The Moose Mountain Member is comprised of a siliceous sandstone with interbedded carbonaceous and argillaceous layers (Gibson, 1985). Thin, less than 50 cm thick, coal seams occur rarely in the Moose Mountain Member.
- The Mist Mountain Formation overlies the Morrissey Formation and bears coal seams with economic potential (Kim, 1976). Locally this formation can be subdivided, from bottom to top, into the Adanac, Hillcrest and Mutz Members (Norris, 1959); regionally, these members are not recognized. The Mist Mountain Formation is comprised primarily of dark-grey siltstone, with lesser sandstone, mudstone, shale and local conglomerate interbeds (Gibson, 1985). Coal seams in the Mist Mountain Formation vary in thickness and can be up to 18 m thick; they range from bituminous in the south to semi-anthracite in rank in the north (Smith et. al, 1994). Progressive south to north changes in depositional environments cause the Mist Mountain Formation to grade into the contemporaneous but mainly coal-barren Nikanassin Formation to the north of Clearwater River (~latitude 52°).
- The Elk Formation overlies the Mist Mountain Formation and is comprised of interbedded sandstone, siltstone, mudstone, shale and chert-pebble conglomerate; however, it is absent in the Crowsnest Pass area (Gibson, 1985).

The Early Cretaceous Blairmore Group overlies the Kootenay Group and is divided into four formations: from bottom to top, the Cadomin, Gladstone, Beaver Mines, and Ma Butte Formations (Gibson, 1985).

- The Cadomin Formation disconformably overlies the Mist Mountain Formation in the Crowsnest area and is comprised of a resistant pebble conglomerate with local quartzose sandstone interbeds. This unit is ridge-forming and is a marker unit for the coal-bearing Kootenay Group immediately below. At Chinook South, this unit forms the Willoughby Ridge and has a typical thickness of 10 to 30 m.
- The Gladstone Formation is divided into two main lithologies, an interbedded mudstone and sandstone and a dark-grey, argillaceous limestone with fossiliferous, calcareous shale.
- The Beaver Mines Formation is characterized by interbedded mudstone and very-fine-grained sandstone, with prominent interbedded coarser sandstone with a sharp base that fines upwards.
- The Ma Butte Formation is primarily comprised of mudstone and very-fine-grained sandstone with lesser interbedded coarser sandstone and common tuffaceous mudstones in the upper part of the formation. The Ma Butte Formation grades into the Crowsnest Formation.

The Late Cretaceous Crowsnest Formation overlies the Blairmore Group and is characterized by bedded pyroclastic and epiclastic deposits consisting of agglomerates, tuffs and volcanic sandstones with minor flows and dikes (Pearce, 1969). Common minerals found in the formation include sanidine, melanite

garnet, aegirine-augite and analcime (Adair and Burwash, 1994). The Crowsnest Formation has a maximum thickness of 426 m.

6.2 Structural Geology

Stratigraphy in the Crowsnest Pass area has been subjected to first and second order faulting, as well as complex folding. The major faults, the Coleman, Isolation and McConnell thrusts, trend north and dip to the west at 08°; they displace the stratigraphy approximately 9.5 to 10 km eastward. They have resulted in the repetition of the Mist Mountain Formation, thickening of coal seams and coal being brought to depths favorable for modern mining methods. This faulting has also complicated the coal geology through shearing and increased ash content and oxidation. Major folds, including the Crowsnest Syncline and Allison Anticline, the Bellevue Syncline and Anticline and the Turtle Mountain Anticline (Rushton et al., 1972), also trend north. Secondary local thrusts trend north, and occur within each thrust sheet, resulting in local structure units or packages affecting coal seam thickness and occurrence (Table 6-1).

Table 6-1 Summary of Thrust Faults

Regional Thrusts Faults	Regional Structural Unit	Local Thrusts Faults
McConnell Thrust	McConnell Thrust Sheet	Mutz Thrust Twin Ridge Thrust
Isolation Thrust	Isolation Thrust Sheet	Hidden Creek
Coleman Thrust	Coleman Thrust Sheet	Vicary Racehorse Rim McGillivray

The Coleman Thrust cuts through the middle of the Mist Mountain Formation and acts as a basal surface to the Chinook Project geological model, as no significant resources are believed to exist below the Coleman Thrust.

Chinook South

Local thickening occurs in the York Creek area by thrust faulting, resulting in zones of uncharacteristically thick coal seams as well as zones of uncharacteristically thin coal seams. At Chinook South several secondary thrust faults occur west of, and associated with, the basal Coleman Thrust. In general, the thrusts dip at higher angles than the coal seams, but locally cut along and parallel to the coal seams. Only one secondary thrust fault at Chinook South was modelled in the 2020 Resource Estimate due to limited available downhole data. The regional strike at Chinook South is approximately 0 degrees and strata dip to the west at 30 to 35 degrees (Norwest, 2005).

Chinook Vicary

Several secondary thrust faults exist at Chinook Vicary with the area being more structurally complex than Chinook South. North of the McGillivray Mine, the Vicary thrust splays off the main Coleman Thrust causing a small repeat of the Cadomin Formation. In the area around the historical Vicary Mine, surface mapping indicates complex surface geology with a series of splay faults and a slip fault with large deformed blocks of Cadomin and Mist Mountain formation. The underground mine plans show coal seam S2 to be relatively planar, offset by a series of splay thrusts, so it is believed the surface deformation is a

result of near surface slip faulting (Smith, 1991). Multiple splay faults continue north of the historical Vicary Mine towards the Project boundary where drillhole data is limited.

Appendix F. Biotic Communities of the Oldman River Watershed

Biotic Properties and Ecological Classification

Variation in elevation (Figure 12), aspect (Figure 12), and climate (Figure 15-Figure 16) of the ORW creates significant spatial variation in soils and plant community structure. The resultant gradient in plant community structure is the basis for distinguishing the 7 different natural subregions that comprise the ORW (Figure 133).

Whereas the composition of the lower regions of the ORW have been transformed considerably in the past century by agriculture, the ORW headwaters remain largely intact in terms of their natural plant communities (see Appendix Figures, including Figure 139, Figure 134-Figure 138). Natural plant communities play an important role in holding and releasing water for surface and subsurface flow and as such it is important that these remaining communities be conserved – particularly in the basin headwaters. The current distribution of wetlands, deciduous forest, mixed forest, conifer forest, and grasslands are mapped and presented in the Appendices (Figure 134-Figure 138).

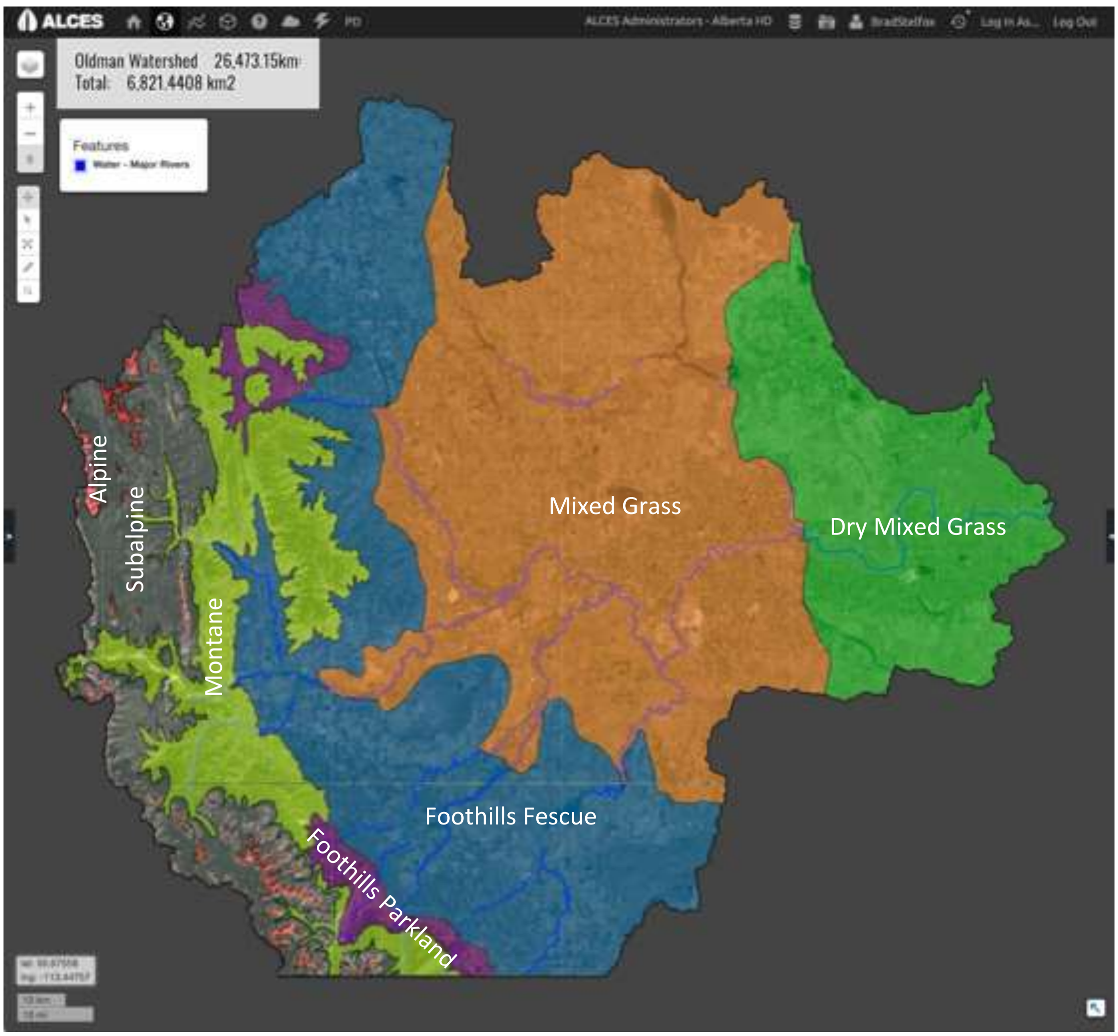


Figure 133. Natural subregions of the ORW.

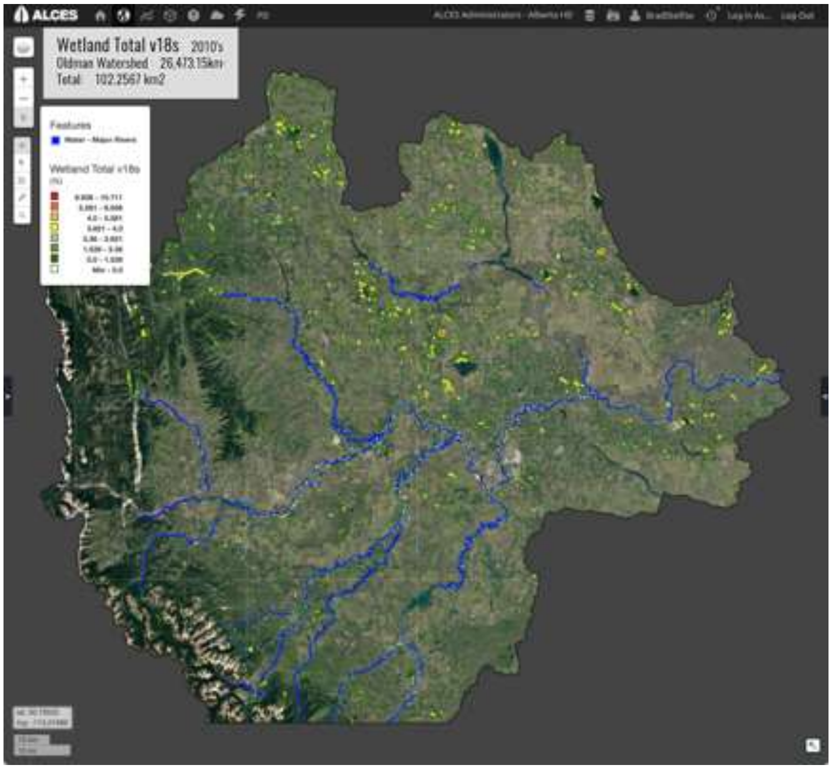


Figure 134. Distribution remaining wetlands in the ORW. Source: Alces Online and ABMI (2018).

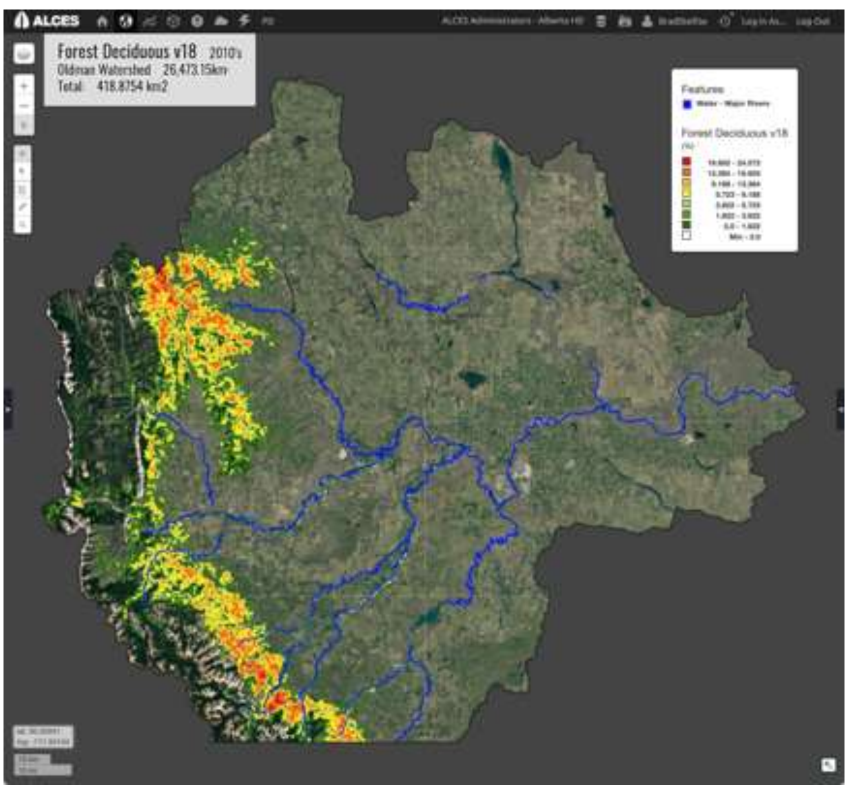


Figure 135. Distribution of Deciduous Forests in the ORW. Source: Alces Online and ABMI (2018).

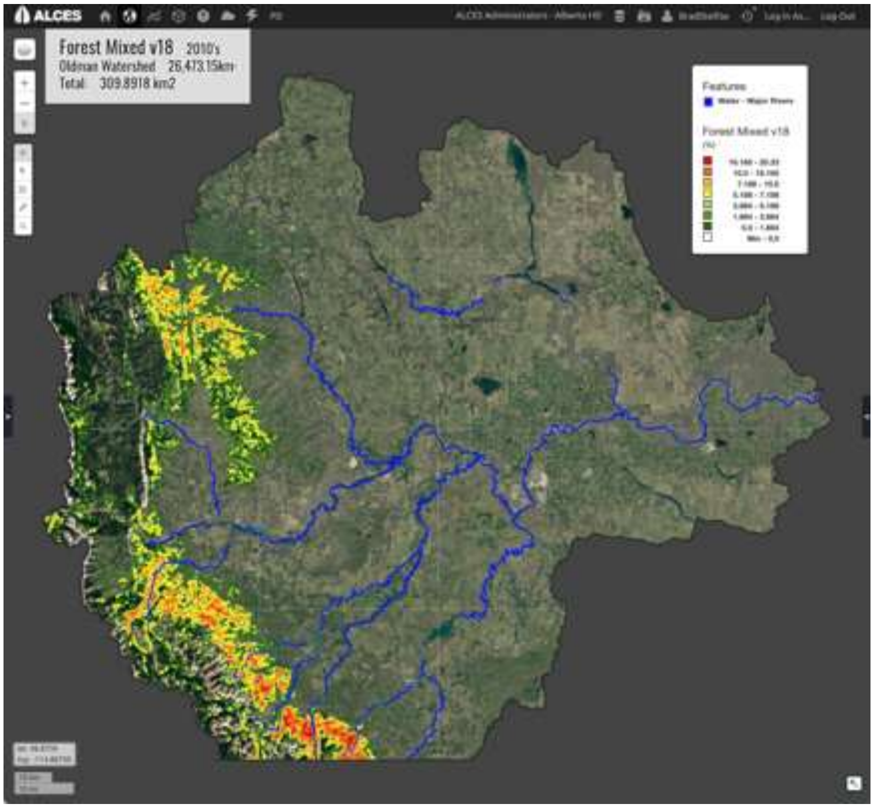


Figure 136. Distribution of Mixed Forests in the ORW. Source: Alces Online and ABMI (2018).

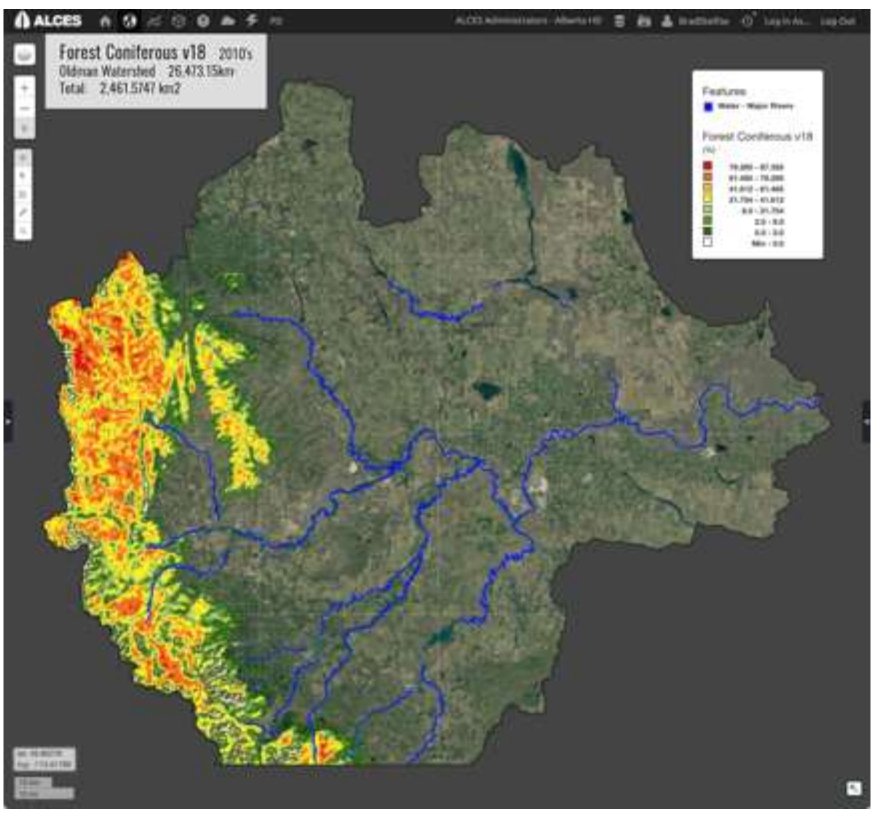


Figure 137. Distribution of Conifer Forests in the ORW. Source: Alces Online and ABMI (2018).

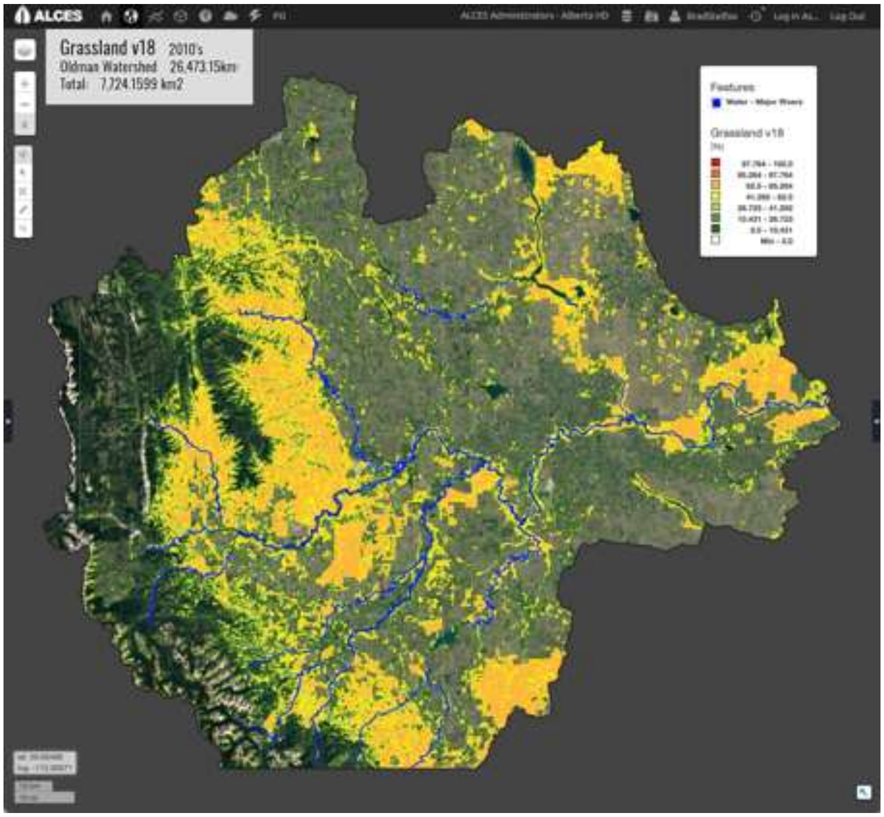


Figure 138. Distribution of remaining grassland in the ORW. Source: Alces Online and ABMI (2018).

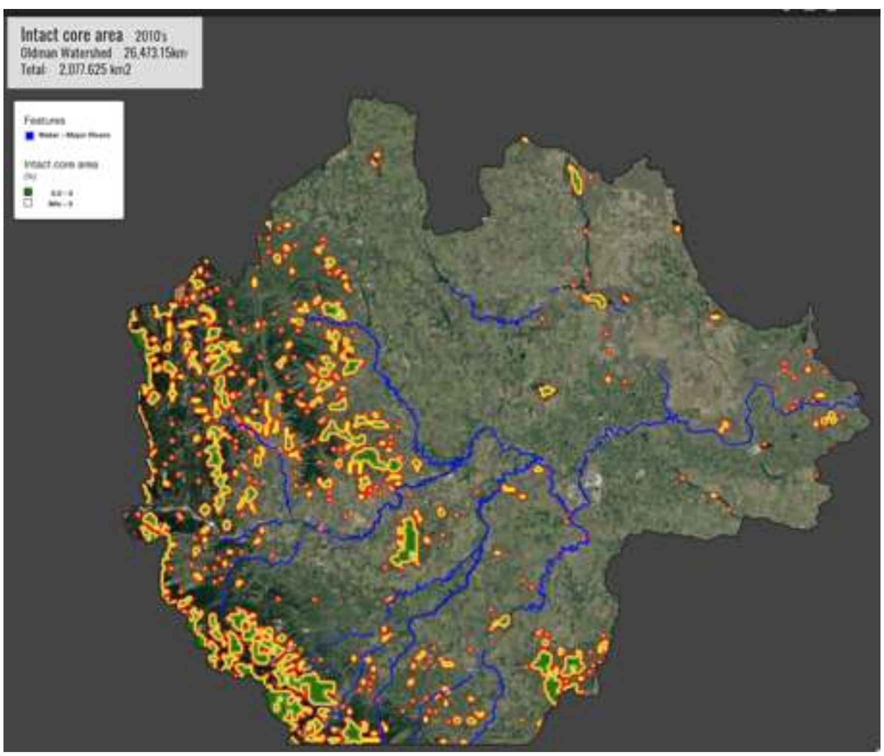


Figure 139. Remaining Core Area of Natural Habitat within the ORW. Source: Alces Online and ABMI 2019.

Appendix G. The Importance of Reference Conditions when discussing Coal Mining and Water Quality

Water quality is the most deeply felt issue in the current conversation of coal mining in the ORW. Given the global literature detailing how coal mining affects water quality and quantity[195], the anxiety of ORW residents is justified. The science tying coal mining to changes in water quality is large (see Clean Air Task Force (2001) and), and ranges across impacts from heavy metals, selenium, PAH, sediment, biodiversity, ecosystem function……

Key to any science-based approach to the coal/water quality nexus, is determining proper reference conditions of water quality in the ORW headwaters. Basically, watershed scientists are trying to get at the answer to the question "In a pre-European era, what was the spatial and temporal variation in the attributes that define water quality, whether they be metals, organics, sediment, turbidity, alkalinity, pH, dissolved oxygen, or any other element that affects ecosystem function or humans and their land use". As one can imagine, this is no easy task, and one that would have been best conducted 200 years ago when our waters reflected entirely the natural dynamics (climate (floods, droughts), fires, plant community succession, landslides) that created the variation in water quality and quantity that would have been witnessed by First Nation communities for thousands of years before the arrival of European lands uses.

Unlike the lower portions of the ORW, the headwaters have minimal land use and are comparatively pristine. That is not to say, however, that the water yielded by these headwaters is chemically "pure" – far from it. Surface and subsurface water is the product of the geology through which it flows, and the "natural" geology of the ORW is one that contains a diverse collection of metals, minerals, and organics, many of which can be toxic, or cause adverse effects, if their concentrations are high. With each passing decade, the ability of water quality laboratories become better in their ability to detect water constituents. Ultra-clean labs can now detect some water constituents at remarkably low concentrations (parts per trillion).

The challenge for the ORW residents is to gain a good empirical understanding of the "Range of Natural Variability (RNV)" of water chemistry, aquatic invertebrates, and wetlands, that collectively maintain ecosystem function and the utility of this water consumed by downstream water users. Learning that selenium, lead, or arsenic is dissolved within the water of the ORW headwaters is not in of itself a reason for alarm – for it would be alarming if they were not there. What would be cause for great concern, however, is whether coal mining (or other land uses) was to result in a significant change in these key elements that would change the ORW water from its RNV condition and constitute a risk to residents, land-use, or ecosystem function. And to get at this key question, we need good reference data. And finding these reference sites is increasingly difficult.

It would have been ideal if the government of Alberta had established a robust network of "protected" reference water sampling sites that were systematically monitored to help Albertans understand water RNV and how it compares to water on our "working" landscape. Sadly, this has not been the case. Our current system of water sampling in the ORW (and elsewhere in Alberta) is generally of low sampling intensity (poor statistical power), incomplete in geographical distribution and the water constituents it measures, poorly funded, and ineffectively conveyed to Albertans who depend on this knowledge.

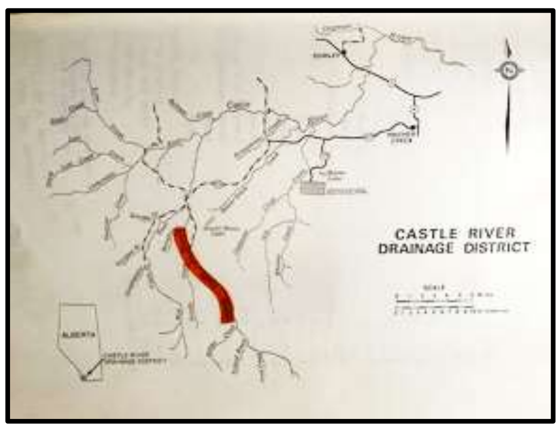
So in the context of this current discussion of coal mining, it is important to get an empirical understanding of the reference condition of water, and to compare those conditions to simulated or measured changes in water caused by any new coal mining that may occur in the ORW. Without proper reference water data, it becomes impossible to know how coal mining is changing the physical and chemical properties of ORW water. Designing an optimal set of water quality reference sites will require understanding the history of coal mining in the region, and that is why there is a section in this report identifying heritage coal mining sites. Ideally, the streams that drain these heritage coal mines would not be considered as candidates for RNV references sites but would be important monitoring sites to see if they differ from reference water sites.

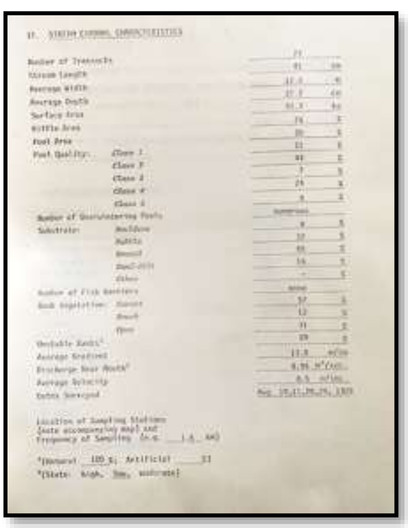
The residents of the ORW headwaters recognize the importance of sampling water before any new coal mining proceeds and are engaging academic and conservation organizations to assist in this regard. Community-based water monitoring (CBWM) is now an active discussion within ORW residents, who are actively exploring how best to sample water quality and aquatic invertebrate communities in the ORW headwaters. Monitoring protocols such as CABIN[196], and the Living Lakes Canada[197] initiative are currently being explored.

Although a historical systematic monitoring program for water quality and aquatic invertebrates does not exist for the ORW headwater basins, there does exist invaluable information collected by periodic Alberta Fish and Wildlife sampling of headwater streams in the 1970s and 1980s. Examples include field research projects examining water quality, fish habitat, and fish populations by Duane Radford, Lorne Fitch, and colleagues. These reports do not exist in digital form but copies do exist in regional Alberta Fish and Wildlife offices. Key reports include:

- Radford, Duane, 1977. A Report on Biological inventories of 17 streams in the Livingstone Drainage district of Alberta. Alberta Fish and Wildlife Division
- Fitch, Lorne, 1978. A report on biological inventories of 11 streams in the Crowsnest drainage district of Alberta. Alberta Fish and Wildlife Division
- Fitch, Lorne, 1979. Castle drainage district stream inventory reports. Alberta Fish and Wildlife Division.
- Fitch, Lorne 1980. The effects of channelization on fish and fish habitat in Racehorse Creek, Alberta. Alberta Fish and Wildlife Division

These reports can help inform discussions about fish habitat and fish populations in drainages receiving previous coal mining, in drainages that have no historical coal mining activity (potential reference systems), and in drainages which proposed new coal mines exist. This type of information can assist scientists in selection of those sampling sites that optimize sampling effort relative to control and treatment sites.





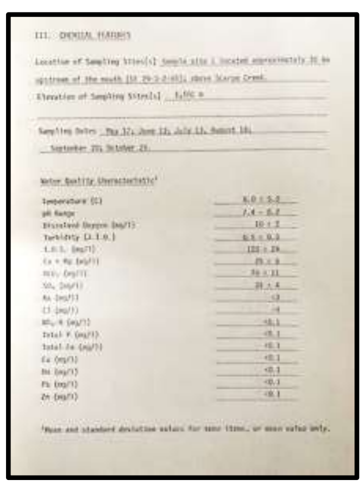
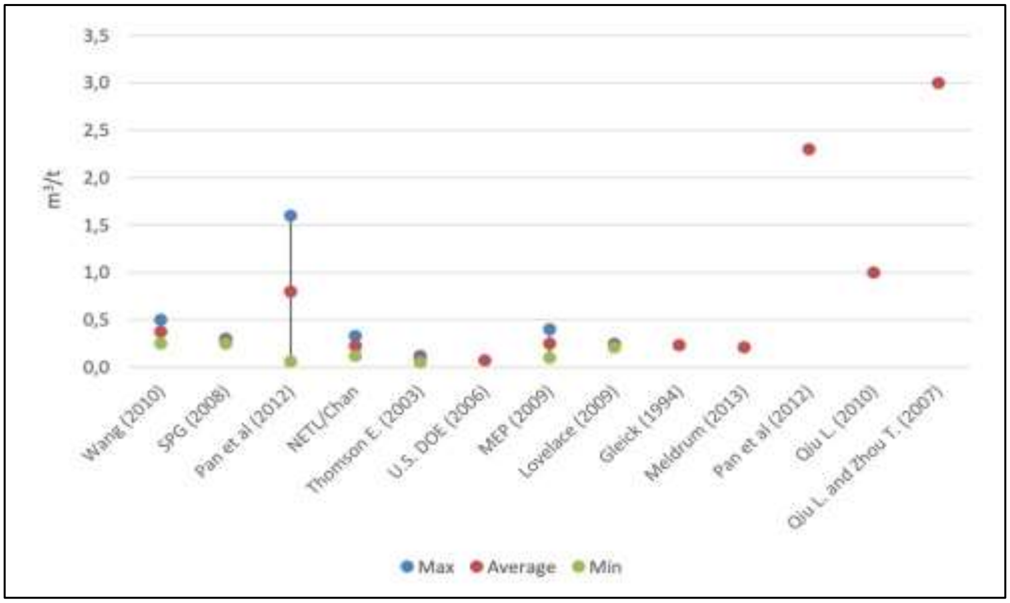


Figure 140. Examples of the types of physical, biotic, and water chemistry indicators collected in these headwater systems in the 1980s.

Appendix H. Water Demand for Coal Mining

Water is required in the extraction, processing, and combustion phases of coal mining[198]. For this project, it is the extraction and processing water demand that is relevant, as the combustion phase water requirements will occur at destination markets where coal is turned into coke for steel production. There is considerable regional and global variation in the water use intensity of coal mining (m^3/tonne of coal) but values generally average about 0.25 m^3/tonne for extraction and about 0.25 m^3/tonne for processing (cleaning)[199] (Figure 141). Water demand intensity is generally much higher in developing countries than in developed countries. For the purposes of this study we used a total gross water use coefficient of 0.204 m^3/tonne of clean coal, based on published information from Grassy Mine. Most published estimates of water use are higher (Figure 141). As such, our project is based on optimistic and low water use metrics as stated by the coal sector. In this sense, our results should be considered as conservative estimates of potential water use.



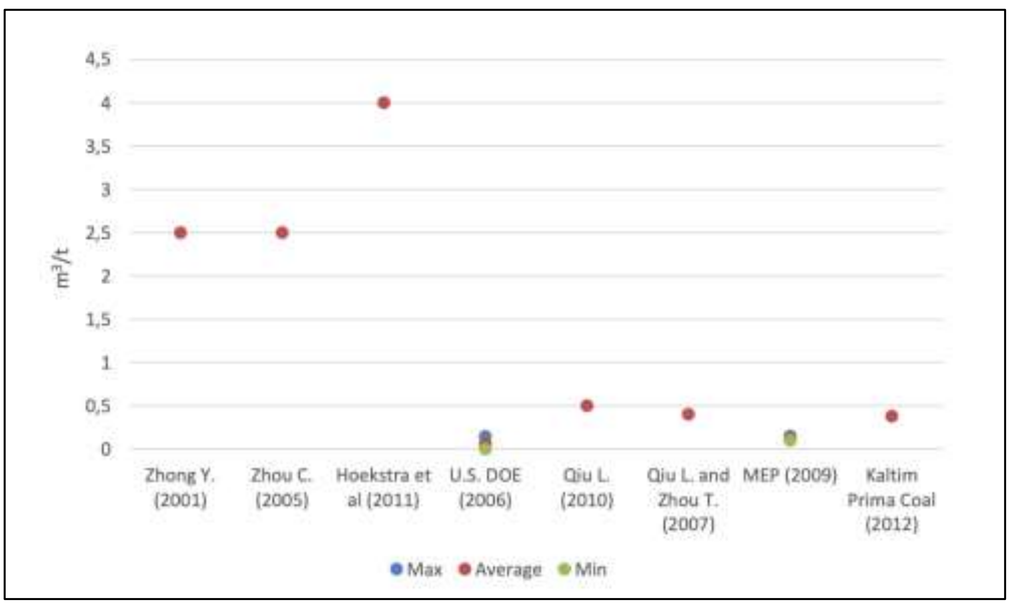


Figure 141. Comparison of water consumption rates for coal mining (above) and coal washing operations (below). Source: E. Olson, 2015. Water Use in China's Coal industry. https://www.diva-portal.org/smash/get/diva2:816658/FULLTEXT02.pdf

Appendix I. Sub-Basins of the ORW

The major (Figure 142) and minor (Figure 143) sub-watersheds of the ORW are shown below.

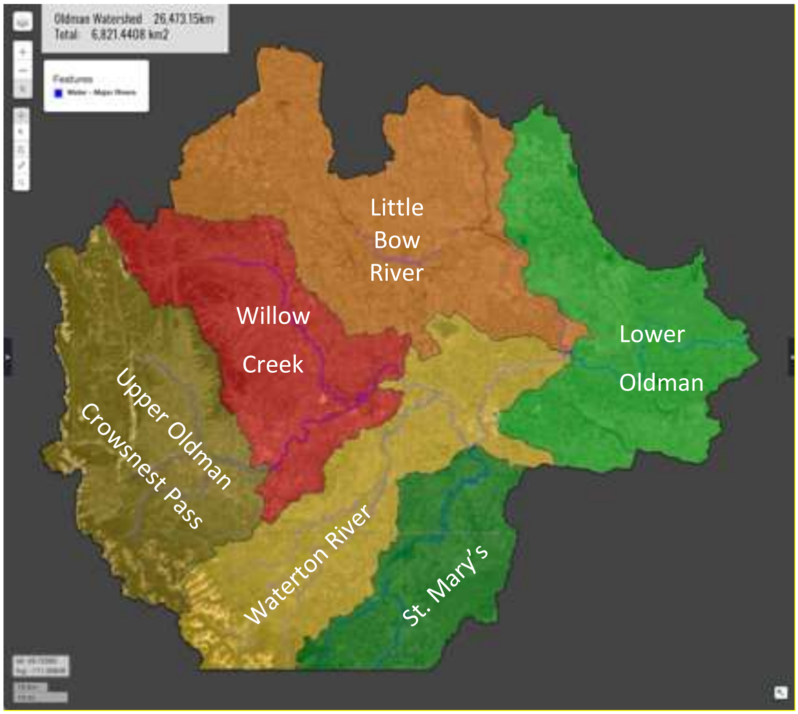


Figure 142. 1st Order watersheds of the ORW. Source: Alces Online.

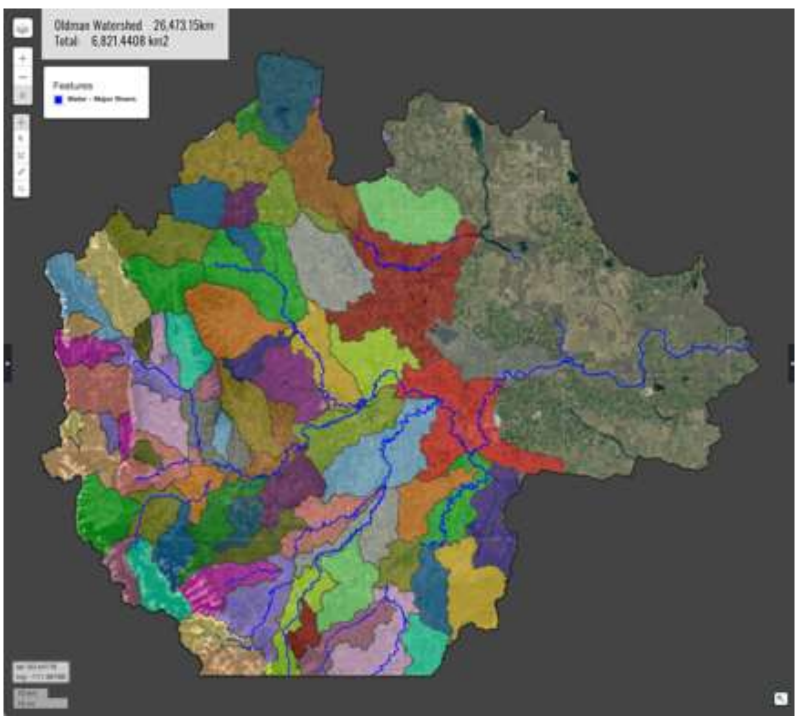


Figure 143. HUC 10 watersheds of the ORW. Source: Alces Online.

References

Section References for Bill Donahue's Chapter on Water Quality

1. Beale, M. M. and M. S. Boyce. 2020. "Mine reclamation enhances habitats for wild ungulates in west-central Alberta." Restoration Ecology **28**(4).
2. Belmer, N., C. Tippler, P. J. Davies and I. A. Wright. 2014. Impact of a coal mine waste discharge on water quality and aquatic ecosystems in the Blue Mountains World Heritage area. 7th Australian Stream Management Conference, Townsville, Queensland.
3. Brinker, C. J., M. D. Symbaluk and J. G. Boorman. 2011. Constructing havitat for a susustainable native fisheries in the Sphinx Lake end pit lake system. Sixth Annual International Conference on Mine Closure, Lake Louise, Canada, Australian Centre for Geomechanics, Perth.
4. Bulltail, G. and M. T. Walter. 2020. "Impacts of coal resource development on surface water quality in a multi-jurisdictional watershed in the western United States." Journal of Contemporary Water Research & Education(169): 79-91.
5. Cannon, M. R., D. A. Nimick, T. E. Cleasby, S. M. Kinsey, et al. 2007. Measured and Estimated Sodium-Adsorption Ratios for Tongue River and its Trbutaries, Montana and Wyoming, 2004-06**:** 45.
6. Carpenter, S. R., N. F. Caraco, D. L. Correll, R. W. Howarth, et al. 1998. "Nonpoint pollution of surface waters with phosphorus and nitrogen." Ecological Applications **8**(3): 559-568.
7. Casey, R. 2005. Results of Aquatic Studies in the McLeod and Upper Smokey River Systems.
8. Casey, R. and P. Siwik. 2000. Overview of selenium in surface waters, sediment and biota of river basins of west-central Alberta. 24th Annual British Columbia Mine Reclamation Symposium, Williams Lake, BC.
9. Chambers, P. A., J. M. Culp, N. E. Glozier, K. J. Cash, et al. 2006. "Northern Rivers Ecosystem Initiative: Nutrients and dissolved oxygen – issues and impacts." Environmental Monitoring and Assessment **113**: 117-141.
10. Giam, X., J. D. Olden and D. Simberlofff. 2018. "Impact of coal mining on stream biodiversity in the US and its regulatory implications." Nature Sustainability **1**: 176-183.
11. Kuchapski, K. A. and J. B. Rasmussen. 2015a. "Food chain transfer and exposure effects of selenium in salmonid fish communities in two watersheds in the Canadian Rocky Mountains." Canadian Journal of Fisheries and Aquatic Sciences **72**: 955-967.
12. Kuchapski, K. A. and J. B. Rasmussen. 2015b. "Surface coal mining influences on macroinvertebrate assemblages in streams of the Canadian Rocky Mountains." Environmental Toxicology and Chemistry **34**(9): 2138-2148.
13. Lemly, A. D. 1996. "Assessing the toxic threat of selenium to fish and aquatic birds." Environmental Monitoring and Assessment(43): 19-35.
14. Lemly, A. D. 1997. "Environmental implications of excessive selenium: a review." Biomedical and Environmental Sciences(10): 415-435.
15. Lindberg, T. T., E. S. Bernhardt, R. Bier, A. M. Helton, et al. 2011. "Cumulative impacts of mountaintop mining on an Appalachian watershed." Proceedings of the National Academy of Sciences **108**(52): 20929-20934.
16. Mahmood, F. N. 2016. Nitrate in Coal Waste Rock Dumps, Elk Valley, British Columbia, Canada. M.Sc., University of Saskatchewan.
17. Miller, L. L., J. B. Rasmussen and V. P. Palace. 2013. "Selenium bioaccumulation in stocked fish as an indicator of fishery potential in pit lakes on reclaimed coal mines in Alberta, Canada." Environmental Management **52**: 72-84.
18. Saffran, K. A. and A.-M. Anderson 2009. Review of Benthic Invertebrates and Epilithic Algae at Long-term Monitoring Sites in the Bow River. A. E. Water Policy Branch, Province of Alberta**:** 36.
19. Sosiak, A. 2002. "Long-term response of periphyton and macrophytes to reduced municipal nutrient loading to the Bow River (Alberta, Canada)." Canadian Journal of Fisheries and Aquatic Sciences **59**: 987-1001.
20. Wayland, M. and R. Crosley. 2005. "Selenium and other trace elements in aquatic insects in coal mine-affected streams in the Rocky Mountains of Alberta, Canada." Arch. Environm. Contam. Toxicol. **50**: 511-522.
21. Weber, B. 2021. Community involvement key to safe, reclaimable coal mines: industry scientists, Canadian Press.

General References

1 Chernos, M., Goodbrand, A., Straker, J., and MacDonald, R.J. 2021. Changes in streamflow and water quality in the upper Oldman River watershed due to climate change and open-pit coal mining development. Prepared for the Livingstone Landowners Group.

2 Livingstone Landowners Group. https://www.livingstonelandowners.net/.

3 Hansford, Jay, and C. Vest. 2005.The Oldman River and the Sacred: A meditation upon Aputosi PII'Kani Tradition and environmental ethics. The Canadian Journal of Native Studies XXV, 2(2005):571-607. http://www3.brandonu.ca/cjns/25.2/cjnsv25no2_pg571-607.pdf.

4 Statistics Canada, 2016 Survey Data Results. https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/index-eng.cfm

5 Pernitsky, D. 2010. Closing the South Saskatchewan River Basin to New Water Licences: Effects on Municipal Water Supplies. Canadian Water Resources Journal 35(1):79-92. https://www.researchgate.net/publication/250390613_Closing_the_South_Saskatchewan_River_Basin_to_New_Water_Licences_Effects_on_Municipal_Water_Supplies.

6 Edgecombe, G.H., Caverhill, P.Z., & Canada. (1911). *Rocky Mountains forest reserve: Report of boundary survey parties*. Ottawa: Govt. Print. Bureau.https://www.worldcat.org/title/rocky-mountains-forest-reserve-report-of-boundary-survey-parties/oclc/53694384.

7 Government of Alberta. 1930. Alberta Natural Resources Act. S.C. 1930, c. 3. Assented to 1930-05-30. https://laws-lois.justice.gc.ca/eng/acts/A-10.6/FullText.html.

8 Petch, A. R. (1985). *Planning integrated resource management in Alberta*. Land Use Policy and Research Branch, Lands Directorate, Environment Canada, Working Paper No. 43 (Ottawa: Minister of Supply and Services Canada, 1985).

9 Tunstell, G. 1962. Watershed management by the Eastern Rockies forest conservation board. Volume 38, Number 1, March 1962. https://pubs.cif-ifc.org/doi/abs/10.5558/tfc38086-1.

10 Kennett, S. 2002. *Integrated resource management in Alberta: Past, present and benchmarks for the future*. Canadian Institute of Resources Law, Occasional Paper No. 11 (Calgary: Canadian Institute of Resources Law, 2002).
11 Brownsey, K., and J. Rayner. 2009. Integrated land management in Alberta: From economic to environmental integration, Policy and Society, 28:2, 125-137, DOI: 10.1016/j.polsoc.2009.05.002.
12 Southern Alberta Land Trust. The changing landscape of the southern Alberta foothills. https://salts.land/wp-content/uploads/2017/04/The-Changing-Landscape-of-the-Southern-Alberta-Foothills-Southern-Foothills-Study-Phase-1-2-website-version.pdf.
13 South Saskatchewan Regional Plan 2014 - 2024 Amended May 2018. https://open.alberta.ca/dataset/13ccde6d-34c9-45e4-8c67-6a251225ad33/resource/e643d015-3e53-4950-99e6-beb49c71b368/download/south-saskatchewan-regional-plan-2014-2024-may-2018.pdf.
14 Southern Alberta Land Trust. The changing landscape of the southern Alberta foothills. https://salts.land/wp-content/uploads/2017/04/The-Changing-Landscape-of-the-Southern-Alberta-Foothills-Southern-Foothills-Study-Phase-1-2-website-version.pdf.
15 Oldman Watershed Council. https://oldmanwatershed.ca/.
16 J, Byrne., S. Kienzle., D. Johnson., G. Duke., V. Gannon., L. Selinger., and J. Thomas. (2006). Current and future water issues in the Oldman River Basin of Alberta, Canada. Water science and technology : a journal of the International Association on Water Pollution Research. 53. 327-34. 10.2166/wst.2006.328.
17 Riley, S. J. 2021. Alberta's back door" plan to free up billions of litres of water for coal mines raises alarm. The Narwhal. Feb 2021. https://thenarwhal.ca/alberta-coal-mining-rockies-oldman-river/.
18 Nitsitapi Water Protectors. (n.d.). https://niitsitapiwaterprotectors.com/our-fight.
19 Alberta Parks. 2018. https://www.albertaparks.ca/albertaparksca/management-land-use/parks-system/.
20 Alberta Wilderness Association. 2021. Protected Areas. https://albertawilderness.ca/issues/wildlands/protected-areas/.
21 Canadian Parks and Wilderness Society. (n.d.). Southern Alberta Chapter. https://cpaws-southernalberta.org/provincial-protected-areas/.
22 Morrison, K and N. Dougall. 2021. Albertans want more protections for the Eastern Slopes. Canadian Parks and Recreation Society. Southern Alberta Chapter. March 26, 2021. https://cpaws-southernalberta.org/albertans-want-more-protections-for-the-eastern-slopes/
23 Livingstone Landowners group. (n.d.). Finding Water Video Series. https://www.livingstonelandowners.net/finding-water-educational-videos
24 Atrum Coal. 2020. Elan Hard Coking Coal Project. December 2020. https://www.atrumcoal.com/projects/elan-project/.
25 Montem Resources. 2021. Tent Mountain Mine. https://montem-resources.com/projects/tent-mountain/.
26 Nikiforuk, A. 2021. When is Mountaintop Removal Not Mountaintop Removal? In Alberta, Of Course! The Tyee. March 5th 2021. https://thetyee.ca/Analysis/2021/03/05/Mountaintop-Removal-Alberta/.
27 Nikiforuk, A. 2021. Critics Skeptical as Alberta Reverses Course on Open-pit Coal Mines. The Tyee. February 8th 2021. https://thetyee.ca/News/2021/02/08/Critics-Skeptical-Alberta-Reverses-Course-Open-Pit-Coal-Mines/.
28 Nikiforuk, A. 2021. Trust Alberta's Energy Regulator to Safeguard Coal Mines? The Tyee. February 3rd 2021. https://thetyee.ca/Analysis/2021/02/03/Trust-Alberta-Energy-Regulator-Safeguard-Coal-Mines/.
29 Fitch, L. 2021. Opinion: Don't let coal's economic promise blind us to the cost. Edmonton Journal. February 6th 2021.https://edmontonjournal.com/opinion/columnists/opinion-dont-let-coals-economic-promise-blind-us-to-the-costs.
30 Fitch, L. 2020. Resource decisions made in a crisis. July 23rd 2020. https://www.producer.com/opinion/resource-decisions-made-in-a-crisis/.
31 Tighem, K. 2021. Opinion: Opening Rockies to coal mining has got Albertans' attention. Edmonton Journal. January 21st 2021.https://edmontonjournal.com/opinion/columnists/opinion-opening-rockies-to-coal-mining-has-got-albertans-attention.
32 Weber, B. 2021. As Alberta debates coal mining, industry already affecting once protected Rockies. Global News. January 21st, 2021. https://globalnews.ca/news/7590265/alberta-coal-mining-affecting-rockies/.
33 Luff, D. 2020. Save The Mountains. Published on YouTube. October 7th 2020. https://www.youtube.com/watch?v=aeawqueXKns.
34 Morrison, K. 2020. Coal in SW AB: What You Need To Know. CPAWS Southern Alberta. Published on YouTube. December 11th 2020. https://www.youtube.com/watch?v=7T3o6Y5sRGQ.
35 Save The Mountains. (2021). https://www.facebook.com/savethemountainrange.
36 Niitsitapi Water Protectors. (n.d.). https://niitsitapiwaterprotectors.com/our-fight.
37 The Canadian Press. 2021. Alberta musician Corb Lund comes out against proposed coal mines in Rocky Mountains. CBC. January 13th 2021. https://www.cbc.ca/news/canada/calgary/corb-lund-coal-mine-opposition-alberta-1.5871428.
38 Lund, C. 2021. Mountains, Not Mines. Posted to Facebook. January 12th 2021. https://www.facebook.com/watch/?v=340961180232532.
39 Marshall, A. 2021. My Thoughts on Alberta's Coal Development Policy. Posted to YouTube. February 2nd 2021. https://www.youtube.com/watch?v=qFksS-HnfQo.
40 Marshall, A. 2021. "For those who have watched my story today…" Posted to Facebook. January 13th 2021. https://www.facebook.com/watch/?v=417450459521358.
41 Ramsay, C., and J. Croteau. 2021. Alberta to reinstate 1976 coal policy revoked last spring after public outcry. Global News. February 8th 2021. https://globalnews.ca/news/7627298/alberta-reinstates-1976-coal-policy/.
42 Wallace, R. (n.d.). Coal Policy Engagement. Alberta.ca. https://www.alberta.ca/coal-policy-engagement.aspx.
43 Bellefontaine, M. 2021. Alberta halts all coal exploration in Foothills and Rockies during consultation. CBC. April 23rd 2021. https://www.cbc.ca/news/canada/edmonton/alberta-halts-all-coal-exploration-in-foothills-and-rockies-during-consultation-1.6000301.
44 Weber, B. 2021. Alberta government announces 5-member coal consultation committee, online survey. Global News. March 20th 2021. https://globalnews.ca/news/7727158/alberta-coal-consultation-committee-announced/
46 Bustin, R.M. and England, T.D.J. 1989. Timing of organic maturation (coalification) relative to thrust faulting in the southeastern Canadian Cordillera. International Journal of Coal Geology, v. 13, p. 317-339.

47 Bustin, R.M. and Smith, G.G. (in press). Coal deposits in the Front Ranges and Foothills of the Canadian Rocky Mountains, southeastern Canadian Cordillera. International Journal of Coal Geology.

47 Boonstra, C. (n.d.). Chapter 33, Coal Resources. Alberta Energy Regulator. https://ags.aer.ca/atlas-the-western-canada-sedimentary-basin/chapter-33-coal-resources.

48 Government of British Columbia. (n.d.). The East Kootenay Coalfields. https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/geology/coalfields/eastkootenay.
49 Dahrouge Geological Consulting. 2020. Coal Resources For The Chinook Project, Alberta, Canada. March 27th 2020. https://montem-resources.com/wp-content/uploads/2020/04/2020-04-09-JORC_Chinook-Project_FINAL_Signed-small.pdf.
50 AMEC Earth and Environmental, Unitech Solutions Inc, Klohn Crippen Berger Ltd, and Marv Anderson and Associates Ltd. 2009. South Saskatchewan River Basin in Alberta, Water Supply Study. 2009. https://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/irr13053/$FILE/ssrb_main_report.pdf.
51 Sauchyn, D. J. and A. B. Beaudoin, 1998: Recent environmental change in the southwestern Canadian prairies. *Can. Geogr.*, **42 ,** 337–353.
52 Sauchyn, D. J. and W. R. Skinner, 2001: A proxy PDSI record for the southwestern Canadian plains. *Can. Water Resour. J.*, **26 ,** 253–272.
53 Schindler, D. W. and W. F. Donahue, 2006: An impending water crisis in Canada's western Prairie Provinces. *Proc. Natl. Acad. Sci.*, **193 ,** 7210–7216. doi:10.1073/pnas.0601568103.
54 AMEC Earth and Environmental, Unitech Solutions Inc, Klohn Crippen Berger Ltd, and Marv Anderson and Associates Ltd. 2009. South Saskatchewan River Basin in Alberta, Water Supply Study. 2009. https://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/irr13053/$FILE/ssrb_main_report.pdf.
55 Oldman Watershed Council. (n.d.). https://oldmanwatershed.ca/maps.
56 https://land-use.alberta.ca/Pages/default.aspx.
57 Alberta.ca. 2021. Environment and Land Use Planning. https://www.alberta.ca/environment-and-land-use-planning-overview.aspx.
58 Aboriginal Affairs and Northern Development. 2003. Natural Resources Transfer Agreement. December 1st, 2003. https://open.alberta.ca/publications/natural-resources-transfer-agreement.
59 Farr, D. A, Braid and S, Slater. 2018. Linear Disturbances in the Livingstone-Porcupine Hills of Alberta: Review of Potential Ecological Responses. June 2018. https://open.alberta.ca/dataset/c157288f-ba13-47f3-8280-673e32dd83c7/resource/d84dc68a-8670-492a-a11e-791215da877f/download/livingstone-porcupine-review.pdf.
60 CowsandFish.org. N. D. Alberta Riparian Habitat Management Society. https://cowsandfish.org/.
61 AMEC Earth & Environmental. 2009. South Saskatchewan River Basin in Alberta Water Supply Study. November 2009. https://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/irr13053/$FILE/ssrb_main_report.pdf
62 Thompson, J. 2018. Southern Alberta Land Trust Society. Oldman Watershed Priority Mapping. April 2018. https://salts.land/wp-content/uploads/2018/05/Oldman-WS-Priority-Technical-Report.pdf.
63 Mehring, M., N. Mehlhaus., E. Ott., and D. Hummel. 2019. A Systematic Review of Biodiversity and Demographic Change: A Misinterpreted Relationship? November 23rd 2019. https://link.springer.com/article/10.1007/s13280-019-01276-w.
64 Blouin, F. 2006. The Southern Headwaters at Risk Project: A Multi-Species Conservation Strategy for the Headwaters of the Oldman River. March 2006. https://open.alberta.ca/dataset/a4d8f46a-b5d1-4b32-8516-e2afc554351b/resource/282716f3-6f88-4c59-be00-ab09c4f72f6d/download/2006-sar106-sharp-multispeciesconservationoldmanriver-vol004-mar2006.pdf.
65 Gardner, A. 2007. The Changing Landscape of the Southern Alberta Foothills. June 2007. https://salts.land/wp-content/uploads/2017/04/The-Changing-Landscape-of-the-Southern-Alberta-Foothills-Southern-Foothills-Study-Phase-1-2-website-version.pdf.
66 Southern Alberta Land Trust. 2007. The changing landscape of the southern Alberta Foothills. https://salts.land/wp-content/uploads/2017/04/The-Changing-Landscape-of-the-Southern-Alberta-Foothills-Southern-Foothills-Study-Phase-1-2-website-version.pdf.
67 Wilkinson, A. 2014. Alberta Environment and Sustainable Resource Development. Species at Risk: A Guide to Endangered and Threatened Species, and Species of Special Concern in Alberta. 2014. https://open.alberta.ca/dataset/d5f03916-aa1a-4c37-acee-354e69a479f0/resource/7bc9e468-740d-4f06-8805-212eb178ffa0/download/speciesatriskguide-aug27-2014.pdf.
68 To Do Canada. 2019. 25 Things To Do in Crowsnest Pass. May 18th, 2019. https://www.todocanada.ca/25-things-crowsnest-pass/.
69 Macnair, R. 2020. Coalmine Expansion Threatens Bighorn Sheep. Wildsight. May 11th, 2020. https://wildsight.ca/2020/05/11/bighorn-sheep-and-their-threatened-habitat/.
70 Poole, K., and R. Serrouya. 2016. Bighorn Sheep Winter Habitat Selection and Seasonal Movements in an Area of Active Coal Mining. ResearchGate. July 2016. https://www.researchgate.net/publication/305524349_Bighorn_sheep_winter_habitat_selection_and_seasonal_movements_in_an_area_of_active_coal_mining.
71 Cristescu, B., G. Stenhouse., and M. Boyce. 2015. Grizzly Bear Diet Shifting on Reclaimed Mines. Science Direct. July 2015.https://www.sciencedirect.com/science/article/pii/S2351989415000694.
72 Cristescu, B. 2013. Grizzly Bear Response to Open-Pit Mining in Western Alberta, Canada. University of Alberta. Spring 2013. https://era.library.ualberta.ca/items/85780a44-7244-4de6-bf29-86b6b4b86a2c.
73 Sander-Green, L. 2020. Deadly Waters: Trout Population Collapse Back Below Teck Coal Mines. Wildsight. March 19th, 2020. https://wildsight.ca/2020/03/19/deadly-waters-trout-population-collapse-below-teck-coal-mines/.
74 Tighem, K. 2021. Objections to Grassy Mountain proposal. Government of Canada, Reference Number 1549. January 12th, 2021. https://iaac-aeic.gc.ca/050/evaluations/proj/80101/contributions/id/49856.
75 Elphick, J., Bailey., J. Berdusco., G. Sword. 2009. Effect of selenium on early life-stage development of Westslope cutthroat trout. U.S. Department of Energy, Office of Scientific and Technical Information. July 1st, 2009. https://www.osti.gov/etdeweb/biblio/21275862.
76 Young M.K., McKelvey, K.S., Jennings T., Carter, K., Cronn R., Keeley E.R., Loxterman J.L., Pilgrim K.L., Schwartz M.K. (2018). The phylogeography of Westslope cutthroat trout. Pages 261-301 in Trotter P, Bisson P, Schultz L, Roper B (editors). Cutthroat Trout: Evolutionary Biology and Taxonomy. Special Publication 36, American Fisheries Society, Bethesda, Maryland.
77 Fisheries and Oceans Canada. 2019. Westslope Cutthroat Trout: recovery strategy and action plan, 2019. https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/recovery/Westslope-cutthroat-trout-2019-proposed.html#toc8.
78 Fisheries and Oceans Canada. 2019. Westslope Cutthroat Trout: recovery strategy and action plan, 2019. https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/recovery/Westslope-cutthroat-trout-2019-proposed.html#toc8.
79 Fisheries and Oceans Canada. 2019. Westslope Cutthroat Trout: recovery strategy and action plan, 2019. https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/recovery/Westslope-cutthroat-trout-2019-proposed.html#toc8.

80 Mayhood, D.W., W. Haskins and M.D. Sawyer. 1997. Cumulative effects on fish, p. 173-187, in Southern East Slopes cumulative effects assessment, edited by M.D. Sawyer, D.W. Mayhood, P. Paquet, R. Thomas, C. Wallis and W. Haskins. Hayduke and Associates Ltd, Calgary, AB. 207 p. http://www.fwresearch.ca/PDFLibrary.html.

81 Mayhood, D. 2000. Provisional evaluation of the status of Westslope cutthroat trout in Canada, p. 579-585, in Proceedings of the biology and management of species and habitats at risk, edited by L. Darling. B.C. Ministry of Environment, Lands, and Parks and University College of the Cariboo, Kamloops, BC. 974 p.

82 Fluker, S. C., and D. W. Mayhood. 2020. Environmental stewardship of public lands? The decline of Westslope cutthroat trout along the eastern slopes of the Rocky Mountains in Alberta. Public Land & Resources Law Review 42:39-79. https://www.researchgate.net/publication/342978970_Environmental_Stewardship_of_Public_Lands_The_Decline_of_Westslope_Cutthroat_Trout_along_the_Eastern_Slopes_of_the_Rocky_Mountains_in_Alberta.

83 Cleator, H., J. Earle, L. Fitch, S. Humphries, M. Koops, K. Martin, D. Mayhood, S. Petry, C. Pacas, J. Stelfox, and D. Wig. 2009. Information relevant to a recovery potential assessment of pure native Westslope cutthroat trout, Alberta population. Fisheries and Oceans Canada, Canadian Science Advisory Secretariat Research Document 2009/036. iii+26 p.

84 https://www.researchgate.net/profile/Marten-Koops/publication/278037271_Information_Relevant_to_a_Recovery_Potential_Assessment_of_Pure_Native_Westslope_Cutthroat_Trout_Alberta_Population/links/557b37a308aeb61eae21c7bd/Information-Relevant-to-a-Recovery-Potential-Assessment-of-Pure-Native-Westslope-Cutthroat-Trout-Alberta-Population.pdf.

85 The Narwhal. 2019. Elk Valley Fish and Fish Habitat Committee Meeting Slide Deck October 21, 2019. https://www.scribd.com/document/456418138/Elk-Valley-Fish-and-Fish-Habitat-Committee-Meeting-Slide-Deck-October-31-2019.

86 Lemly, A.D. 2014. Review of Environment Canada's Teck Coal Environmental Assessment and Evaluation of Selenium Toxicology Tests on Westslope Cutthroat Trout in the Elk and Fording Rivers in Southeast British Columbia. https://www.teck.com/media/2014-Water-review_environment_canada-T3.2.3.2.1.pdf.

87 Sweetgrass Consultants Ltd. 1997. Environmentally Significant Areas of Alberta. Volumes 1, 2 and 3. https://albertaparks.ca/media/3194487/esa_ab_vol1.pdf.

88 Potyondi, Barry. 1992. Where the rivers meet. A history of the Upper Oldman River Basin to 1939. Printed by Robins Southern Printing. Lethbridge.

89 AMEC Earth and Environmental, Unitech Solutions Inc, Klohn Crippen Berger Ltd, and Marv Anderson and Associates Ltd. 2009. South Saskatchewan River Basin in Alberta, Water Supply Study. 2009. https://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/irr13053/$FILE/ssrb_main_report.pdf.

90 Oldman River State of the Watershed Report. https://static1.squarespace.com/static/55775efbe4b02c5614691727/t/55b9bb34e4b03eb4128ffb5c/1438235444630/CH7OverviewOfTheWatershed.pdf.

91 Oldman Watershed Council. (n.d.). Chapter 7: Overview of the Watershed. https://static1.squarespace.com/static/55775efbe4b02c5614691727/t/55b9bb34e4b03eb4128ffb5c/1438235444630/CH7OverviewOfTheWatershed.pdf.

92 Statistics Canada. 2011-2017. Potable Water Use by Sector and Average Daily Use. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3810027101.

93 Anonymous. (n.d.). Drinking Water Report - Alberta Municipal Benchmarking Initiative.

94 Oldman Watershed Council. (n.d.). The Oldman River and the Sacred. A Meditation upon Aputosi Pii'kani Tradition and Environmental Ethics. https://oldmanwatershed.ca/history.

95 Passelac-Ross, M and C, Smith. 2010. Defining Aboriginal Rights to Water in Alberta: Do They Still "Exist"? How Extensive Are They? Canadian Institute of Resources Law. April 2010. https://cirl.ca/sites/default/files/Occasional%20Papers/Occasional%20Paper%20%2329.pdf.

96 AMEC. 2009. South Saskatchewan River Basin in Alberta: Water Supply Study. Alberta Agriculture and Rural Development. Lethbridge, Alberta.https://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/irr13053/$FILE/ssrb_main_report.pdf

97 Anonymous. 2021. Alberta Irrigation Districts Association. https://aipa.ca/.

98 Ward, D. 2019. Water Requirements for Livestock. Ministry of Agriculture, Food and Rural Affairs. January 2019. http://www.omafra.gov.on.ca/english/engineer/facts/07-023.htm#2.

99 Ding, S., Zhang, Y., Liu, B. *et al.* 2013. Effects of riparian land use on water quality and fish communities in the headwater stream of the Taizi River in China. *Front. Environ. Sci. Eng.* **7,** 699–708 (2013). https://doi.org/10.1007/s11783-013-0528-x.

100 Dodds, W.K., Oakes, R.M. 2008. Headwater Influences on Downstream Water Quality. *Environmental Management* **41,** 367–377 (2008). https://doi.org/10.1007/s00267-007-9033-y.

101 Morrison, K and N, Dougall. 2021. Canadian Parks and Wilderness Society, Southern Alberta Chapter. March 26th 2021. https://cpaws-southernalberta.org/albertans-want-more-protections-for-the-eastern-slopes/.

102 Union of Concerned Scientists. 2017. Coal and Water Pollution. December 6th 2017. https://www.ucsusa.org/resources/coal-and-water-pollution.

103 Munawer, M. 2018. Human health and environmental impacts of coal combustion and post-combustion wastes. ScienceDirect. 2018. https://www.sciencedirect.com/science/article/pii/S2300396017300551.

104 Mishra, V. 2008. Heavy metal pollution induced due to coal mining effluent on surrounding aquatic ecosystem and its management through naturally occurring aquatic macrophytes. ScienceDirect. March 2008. https://www.sciencedirect.com/science/article/abs/pii/S0960852407002246.

105 Linnitt, C. 2018. For decades B.C. failed to address selenium pollution in the Elk Valley. Now no one knows how to stop it. The Narwhal. December 4th 2018. https://thenarwhal.ca/for-decades-b-c-failed-to-address-selenium-pollution-in-the-elk-valley-now-no-one-knows-how-to-stop-it/.

106 Lemly, D. 2019. Environmental hazard assessment of Benga Mining's proposed Grassy Mountain Coal Project. ScienceDirect. June 2019. https://www.sciencedirect.com/science/article/abs/pii/S1462901118313339.

107 Xiaofang, L. 2013. Understanding the salinity issue of coal mine spoils in the context of salt cycle. Springer Link. October 2013. https://link.springer.com/article/10.1007/s10653-013-9573-4.

108 Union of Concerned Scientists. Published July 2008, Updated in 2017. Coal and Air Pollution. December 19th, 2017. https://www.ucsusa.org/resources/coal-and-air-pollution.

109 Pond, G. 2011. Biodiversity loss in Appalachian headwater streams (Kentucky, USA): Plecoptera and Trichoptera communities. Research Gate. January 2011. Https://www.researchgate.net/profile/Gregory-Pond/publication/257568995_Biodiversity_loss_in_Appalachian_headwater_streams_Kentucky_USA_Plecoptera_and_Trichoptera_communities/links/00b495320db5c7335b000000/Biodiversity-loss-in-Appalachian-headwater-streams-Kentucky-USA-Plecoptera-and-Trichoptera-communities.pdf.

110 Simple Charts That Explain The Global Carbon Budget. (n.d.) http://shrinkthatfootprint.com/explain-carbon-budget.

111 Shrink That Footprint. (n.d.). 9 Simple Charts That Explain The Global Carbon Budget. https://www.carbonbrief.org/coal-mines-emit-more-methane-than-oil-and-gas-sector-study-finds.

112 EIA. 2017. Carbon intensity of energy use is lowest in U.S. industrial and electric power sectors. U.S. Energy Information Administration. May 1st 2017. https://www.eia.gov/todayinenergy/detail.php?id=31012.

113 https://www.google.com/search?q=how+does+c02e+of+coal+compare&tbm=isch&ved=2ahUKEwjExf3SvIrwAhXzFjQIHZUyDqgQ2-cCegQIABAA&oq=how+does+c02e+of+coal+compare&gs_lcp=CgNpbWcQAzoECCMQJzoCCAA6BQgAELEDOggIABCxAxCDAToECAAQQzoECAAQGDoGCAAQChAYULPCBVih7QVg8e0FaABwAHgAgAFbiAHRD5IBAjI5mAEAoAEBqgELZ3dzLXdpei1pbWfAAQE&sclient=img&ei=oY19YITxJfOt0PEPleW4wAo&bih=1137&biw=2093&rlz=1C5CHFA_enAU840AU840#imgrc=aMc7mpJSotJi3M.

114 Jordaan, Sarah & Keith, David & Stelfox, Brad. (2009). Quantifying land use of oil sands production: A life cycle perspective. Environ. Res. Lett. 4. 24004-15. 10.1088/1748-9326/4/2/024004.

115 Healing, D. 2020. Alberta set to retire coal power by 2023, ahead of 2030 provincial deadline. Global News. December 4th 2020. https://globalnews.ca/news/7502144/alberta-coal-power-ahead-of-schedule/#:~:text=Environment-,Alberta%20set%20to%20retire%20coal%20power%20by,ahead%20of%202030%20provincial%20deadline&text=Alberta%20is%20set%20to%20meet,recently%20announced%20utility%20conversion%20projects.

116 Alberta.ca. 2021. Phasing out emissions from Coal. https://www.alberta.ca/climate-coal-electricity.aspx.

117 Government of Canada. 2018. Taking action to phase out coal power. Environment and Climate Change Canada. April 23rd 2018. https://www.canada.ca/en/environment-climate-change/news/2017/11/taking_action_tophase-outcoalpower.html.

118 Johnson, L. 2021. Notley introduces bill to curb coal mining and halt exploration in Alberta's Rocky Mountains. Edmonton Journal. April 7th 2021. https://edmontonjournal.com/news/politics/notley-introduces-bill-to-curb-coal-mining-and-halt-exploration-in-albertas-rocky-mountains.

119 https://www.cbc.ca/news/canada/calgary/ndp-coal-mining-legislation-1.5978409#:~:text=Alberta's%20Opposition%20NDP%20will%20introduce,of%20the%20province%20and%20pause.

120 Weber, B. 2021. Alberta legislature turns down NDP request for debate on Rockies coal mining. Global News. April 19th 2021. https://globalnews.ca/news/7772015/alberta-legislature-ndp-debate-bill-rockies-coal/.

121 Government of British Columbia. (n.d.). The East Kootenay Coalfields https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/geology/coalfields/eastkootenay.

122 Sander-Green, S. 2020. Do We Really Need Coal To Make Steel? Wildsight. June 1st 2020. https://wildsight.ca/2020/06/01/do-we-really-need-steelmaking-coal/.

123 Cortes-Ramirez, J. 2018. Mortality and morbidity in populations in the vicinity of coal mining: a systematic review. BMC Public Health. June 11th 2018. https://bmcpublichealth.biomedcentral.com/articles/10.1186/s12889-018-5505-7.

124 Finkelman, R, A, Wolfe and M, Hendryx. 2021. The future environmental and health impacts of coal. Science Direct. April 2021. https://reader.elsevier.com/reader/sd/pii/S2666759220300706?token=F3DE1F707C45E5BF68DE2F2D628F636EED9F5EF07274BF153F8AD4B1A5C92C2C03B8DF8C2720D6AA0F5C33EE8AF91D65&originRegion=us-east-1&originCreation=20210424133359.

125 Chan, L. 2020. A Review of Human Health Impacts of Selenium in Aquatic Systems. July 24th 2020. https://www.ijc.org/sites/default/files/2020-09/HPAB_SeleniumHealthReview_2020.pdf.

126 Anderson, S and J, Meade. 2014. Potential Health Effects Associated with Dermal Exposure to Occupational Chemicals. US National Library of Medicine National Institutes of Health. December 17th 2014. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4270264/.

127 Healthwise Staff. 2019. Black Lung Disease. Healthlink BC. August 22nd 2019. https://www.healthlinkbc.ca/health-topics/ug1566spec.

128 MacCallum, B.N. 1991. Bighorn sheep use of an open pit coal mine in the foothills of Alberta (Unpublished master's thesis). University of Calgary, Calgary, AB. doi:10.11575/PRISM/16843.

129 MacCallum, B.N. 1992. Mountain restoration. Soil and surface wildlife habitat. GeoJournal 27: 23-46.

130 Kneteman, J.G. 2016. Resilient Space: Bighorn Sheep (Ovis canadensis) Ecological Resilience in the Northern Rocky Mountains. A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Ecology, Department of Biological Sciences University of Alberta.

131 Feng, W., C. Wang., L. Xiaohui., H. Wang., and Z. Xueilang. 2020. Distribution of Nitrate Content in Groundwater and Evaluation of Potential Health Risks: A Case Study of Rural Areas in Northern China. December 10th 2020. https://www.mdpi.com/1660-4601/17/24/9390

132 Forsyth, B., A. Cameron., and S. Miller. (n.d.). Explosives and Water Quality. http://pdf.library.laurentian.ca/medb/conf/Sudbury95/GroundSurfaceWater/GSW16.PDF.

133 Teck Resources. 2019. Helping to Protect Water Quality with New Blasting Practices that Reduce Nitrate at the Source. Teck.com https://www.teck.com/news/stories/2020/helping-to-protect-water-quality-with-new-blasting-practices-that-reduce-nitrate-at-the-source.

134 Teck Resources. 2019. Helping to Protect Water Quality with New Blasting Practices that Reduce Nitrate at the Source. Teck.com https://www.teck.com/news/connect/issue/volume-27,-2019/table-of-contents/ideas-at-work-new-blasting-practices-to-protect-water-quality.

135 Government of Alberta.ca. (n.d.). Guidelines for Mines. https://www.alberta.ca/land-conservation-and-reclamation-guidelines-for-mines.aspx#jumplinks-1.

136 McKenna, G. (n.d.). Landform Design Institute. https://www.landformdesign.com/bios.html.

137 Cassie J & McKenna G. 2016. Mine closure planning, design and implementation: from hand-waving to reality. Planning for Closure 2016: First International Congress on Planning for Closure of Mining Operations. Santiago, Chile. November 20-22. Gecamin. Santiago. 9p.

138 (n.d.). Alberta Liabilities Disclosure Project. https://www.aldpcoalition.com/

140 Teck Resources.(n.d.). Responsible Mine Closure & Reclamation. Teck. https://www.teck.com/media/Responsible-Mine-Closure-and-Reclamation.pdf.

140 Foote, L. 2012. Threshold considerations and wetland reclamation in Alberta’s mineable oil sands. Ecology and Society 17(1): 35. http://dx.doi.org/10.5751/ES-04673-170135

141 Auditor General of Alberta. 2015. Environment and Parks and the Alberta Energy Regulator— Systems to Ensure Sufficient Financial Security for Land Disturbances from Mining. July 2015. https://www.oag.ab.ca/wp-content/uploads/2020/05/EP_PA_July2015_AER_Systems_Ensure_Fin_Security_Land_Disturb.pdf.
143 Global Greens Destination. https://greendestinations.org/
143 Alberta Southwest Regional Alliance. 2021. https://www.albertasouthwest.com/about/our-projects/current-projects/sustainable-top-100-destination/.
145 https://greendestinations.org/programs-and-services/top-100-destinations/
145 Econometric Research Ltd. 2011. The Economic Impact of Tourism in Kananaskis Country in 2011 Summary of Findings of the ERL Report. https://open.alberta.ca/dataset/bdfecac0-0dda-4e8c-8321-7002a5edb11c/resource/d4e967af-6d78-4f35-9685-9e6bc68bfce2/download/ei-of-tourism-in-kananaskis.pdf.
146 Ogge, M. 2019. It's time to fight the coal lobby's corrosive influence on our democracy. The Fifth Estate. November 12th 2019. https://thefifthestate.com.au/energy-lead/fight-the-coal-lobbys-corrosive-influence-on-our-democracy/.
147 Nikiforuk, A. 2020. Alberta Coal Grab: What Is the Sound of One Group Lobbying? The Tyee. August 3rd 2020. https://thetyee.ca/Analysis/2020/08/03/Alberta-Coal-Grab-Sound-One-Group-Lobbying/.
148 Riley, S. 2021. The end of an era: how the global steel industry is cutting out coal. The Narwhal. May 1st 2021. https://thenarwhal.ca/steel-coal-mining-hydrogen/.
149 Silverstein, K. 2021. We Could Be Making Steel From Green Hydrogen, Using Less Coal. Forbes. January 25th 2021. https://www.forbes.com/sites/kensilverstein/2021/01/25/we-could-be-making-steel-from-green-hydrogen-using-less-coal/?sh=1dc49f5c3e5c.
150 Cab Direct. 2021. https://www.cabdirect.org/cabdirect/abstract/20083294691.
151 (n.d.). Richest nations agree to end support for coal production overseas. The Guardian. https://www.theguardian.com/environment/2021/may/21/richest-nations-agree-to-end-support-for-coal-production-overseas.
152 Ryan Driskell Tate, Christine Shearer, and Andiswa Matikinca. 2021. Deep Trouble. Tracking Global coal mine proposals. https://globalenergymonitor.org/wp-content/uploads/2021/05/CoalMines_2021_r4.pdf
153 Minister of Environment and Climate Change. 2018. Assessing Cumulative Environmental Effects under the Canadian Environmental Assessment Act, 2012. https://www.canada.ca/en/impact-assessment-agency/services/policy-guidance/assessing-cumulative-environmental-effects-ceaa2012.htm

154 Duinker, P., and L. Greig. 2006. The Impotence of Cumulative Effects Assessment in Canada: Ailments and Ideas for Redeployment. ResearchGate. March 2006. https://www.researchgate.net/publication/7408890_The_Impotence_of_Cumulative_Effects_Assessment_in_Canada_Ailments_and_Ideas_for_Redeployment.
155 Council of Canadian Academics. 2019. Greater Than the Sum of Its Parts: Towards Integrated Natural Resource Management in Canada. CCA Reports. Printed in 2019 in Ottawa, Canada. https://cca-reports.ca/wp-content/uploads/2019/04/Report-Greater-than-the-sum-of-its-parts-toward-integrated-natural-resource-management-in-Canada.pdf.
156 Alberta.ca. Environmental Impact Analysis – Current Projects. https://www.alberta.ca/environmental-impact-assessments-current-projects.aspx.
157 2021. Riversdale Resources. http://www.rivresources.com/site/content/.
158 2021. Environmental Assessment - Montem Resources Alberta Operations Ltd. Tent Mountain Project. Government of Alberta. February 17th 2021. https://open.alberta.ca/publications/environmental-assessment-montem-tent-mountain.
159 (n.d.). The East Kootenay Coalfields. https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/geology/coalfields/eastkootenay.
160 Anonymous. 2018. Elk Valley Cumulative Effects Assessment and Management Report. Elk Valley CEMF. December 2018.https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/cumulative-effects/draft_elk_valley_ceam_12122018.pdf.
161 Atrum Coal. 2020. Elan Hard Working Coal Project. Atrum Coal. https://www.atrumcoal.com/projects/elan-project/.
162 Hong, B.D., and E. R. Slatick. 1994. Carbon Dioxide Emission Factors for Coal. U.S. Energy Information Administration. January-April 1994. https://www.eia.gov/coal/production/quarterly/co2_article/co2.html.
163 Coalbed methane outreach program. United States Environmental Protection Agency. https://www.epa.gov/cmop/coal-mine-methane-sources.
164 Global Energy Monitor. https://globalenergymonitor.org/projects/global-coal-mine-tracker/dashboard/.
166 Government of Canada. 2021. Progress towards Canada's greenhouse gas emissions reduction target. https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/progress-towards-canada-greenhouse-gas-emissions-reduction-target.html
166 Meyer, J.L., Strayer, D.L., Wallace, B., Eggert, S.L., Helfman, G.S., and N.E. Leonard. 2007. The contribution of headwater streams to biodiversity in River Networks. JAWRA. Volume 43 (1); pp 86-103.
167 Alberta Biodiversity and Monitoring Institute. ABMI Data & Analytics Portal. ABMI. https://www.abmi.ca/home/data-analytics.
168 Costello, A. 2006. Status of the Westslope Cutthroat Trout in Alberta. Fish & Wildlife Division. December 2006. https://www.ab-conservation.com/downloads/AWSR/Reptile%20Amphibian%20and%20Fish%20Reports/Status%20of%20Westslope%20Cutthroat%20Trout%20in%20Alberta_2006.pdf.
169 Anonymous. (n.d.). Bull Trout FSI. Alberta.ca. https://www.alberta.ca/bull-trout-fsi.aspx.
170 Costello, A.B. 2006. Status of the Westslope cutthroat trout in Alberta. Prepared for Alberta Sustainable Resources Development. https://open.alberta.ca/dataset/c01f7c84-667f-4e15-a927-fe75a85b91cb/resource/793375ef-e090-4649-a415-82e88197385b/download/2006-sar-statusWestslopecutthroattroutalberta-dec2006.pdf.
171 2021. Coal.ca https://www.coal.ca/.
172 Williams, C. 2019. From Canadian Coal Mines, Toxic Pollution That Knows No Borders. Yale Environment 360. April 1st 2019. https://e360.yale.edu/features/from-canadian-coal-mines-toxic-pollution-that-knows-no-borders.
173 Linnitt, C. 2020. Unique B.C. trout population suffers 93 per cent crash downstream of Teck's Elk Valley coal mines. The Narwhal. April 16th 2020. https://thenarwhal.ca/teck-resources-elk-valley-mines-bc-fish/.
174 Walter, L. 2009. Research Examines the Financial, Health Costs of Coal Mining. EHS Today. June 23rd 2009. https://www.ehstoday.com/health/article/21905872/research-examines-the-financial-health-costs-of-coal-mining.
175 Geis, E. 2017. The Real Cost of Energy. Nature.com. November 29th 2017. https://www.nature.com/articles/d41586-017-07510-3.

176 The Canadian Press. 2021. Alberta didn't consider impact of mountain coal mining on tourism: official. CBC. April 22nd 2021. https://www.cbc.ca/news/canada/calgary/alberta-coal-mining-tourism-1.5999194.
177 Whelan, P. 2021. Selenium from open-pit coal mining may pose downstream risk to ag. Canadian Cattlemen Beef Magazine. April 8th 2021. https://www.canadiancattlemen.ca/news/selenium-from-open-pit-coal-mining-may-pose-downstream-risk-to-ag/.
178 Griffiths, M., S. Wilson., and M. Anielski. 2001. The Alberta GPI Accounts: Fish and Wildlife. September 1st 2001. https://www.jstor.org/stable/resrep00143.7?refreqid=excelsior%3A2fec004505831283161bf443248a242a&seq=1#metadata_info_tab_contents.
179 Merovich, J., N. Hitt., E. Merriam., and J. Jones. 2020. Response of Aquatic Life to Coal Mining in Appalachia. Springer Link. November 26th 2020. https://link.springer.com/chapter/10.1007%2F978-3-030-57780-3_10.
180 Sander-Green, L. 2020. Deadly Waters: Trout Population Collapse Below Teck Coal Mines. Wildsight. March 19th, 2020. https://wildsight.ca/2020/03/19/deadly-waters-trout-population-collapse-below-teck-coal-mines/.
181 Mayhood, D. (n.d.). Provisional Evaluation of the Status of Westslope Cutthroat Trout in Canada. https://fwresearch.ca/Library_files/Mayhood%202000maps.pdf.
182 Alberta Tourism Indicators. TravelAberta.ca. https://industry.travelalberta.com/visitor-market-insight/tourism-indicators/alberta-tourism-indicators#:~:text=In%202019%2C%20the%20economic%20impact,indirect%20and%20%241.1%20billion%20induced).
183 Water Allocation Policy for Closed River Basins in the South Saskatchewan River Basin Directive Environment and Parks, Water Conservation, 2016, No. 3 © 2016 Government of Alberta. https://open.alberta.ca/publications/water-allocation-policy-for-closed-river-basins-in-the-south-saskatchewan-river-basin.
184 Crowsnest Heritage. http://www.crowsnestheritage.ca/history/hillcrest/.
185 Coal Map Mine Viewer. Alberta Energy Regulator. https://extmapviewer.aer.ca/AERCoalMine/Index.html.
186 Kinnear, J. Elk Valley Coal News. https://elkvalleycoal.com/history/.
187 Coal Map Mine Viewer. Alberta Energy Regulator. https://extmapviewer.aer.ca/AERCoalMine/Index.html.
188 Riversdale Resources. http://www.rivresources.com/site/Projects/grassy-mountain-project2/overview3.
189 Montem Resources. https://montem-resources.com/projects/tent-mountain/.
190 2019. Elan Hard Coking Coal Project. Atrum Coal. September 5th 2019. https://atrumcoal.com/wp-content/uploads/2020/01/ATU_Institutional_and_Analyst_Elan_Site_Visit_Presentation.pdf.
191 Atrum Coal. https://www.atrumcoal.com/projects/elan-project/.
192 Montem Resources. https://montem-resources.com/projects/.
193 Dahrouge Geological Consulting. 2020. Coal Resources for the Chinook Project, Alberta, Canada. Montem Resources. April 9th 2020. *https://montem-resources.com/wp-content/uploads/2020/04/2020-04-09-JORC_Chinook-Project_FINAL_Signed-small.pdf.*
194 Gorham, J. , Bradley Ulry, Matthew Carter, Nathan Schmidt. 2020. Coal resources for the chinook project, Alberta, Canada. Prepared for Montem Resources, Alberta Operations Ltd. Competent Persons Report. Prepared by Dahrouge Geological Consulting, Edmonton, Alberta.
195 Zhengfu, B., H. I INYANG., J. L. DANIELS., F. OTTO., and S. STRUTHERS 2010. Environmental issues from coal mining and their solutions, Mining Science and Technology (China), Volume 20, Issue 2, 2010, Pages 215-223.
196 2019. Canadian Aquatic Biomonitoring Network. Government of Canada. November 5th 2019. https://www.canada.ca/en/environment-climate-change/services/canadian-aquatic-biomonitoring-network.html.
197 Living Lakes Canada. https://livinglakescanada.ca/.
198 Cote, C,J. Moran, Christopher, Hedemann, Koch, C. 2010. Systems modelling for effective mine water management. Science Direct. December 2010. https://www.sciencedirect.com/science/article/abs/pii/S136481521000201X.
199 Olsson, E. 2015. Water use in the Chinese coal industry. Uppsala Universitet. 2015. https://www.diva-portal.org/smash/get/diva2:816658/FULLTEXT02.pdf.